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The Journal of
THE ROYAL AERONAUTICAL SOCIETY

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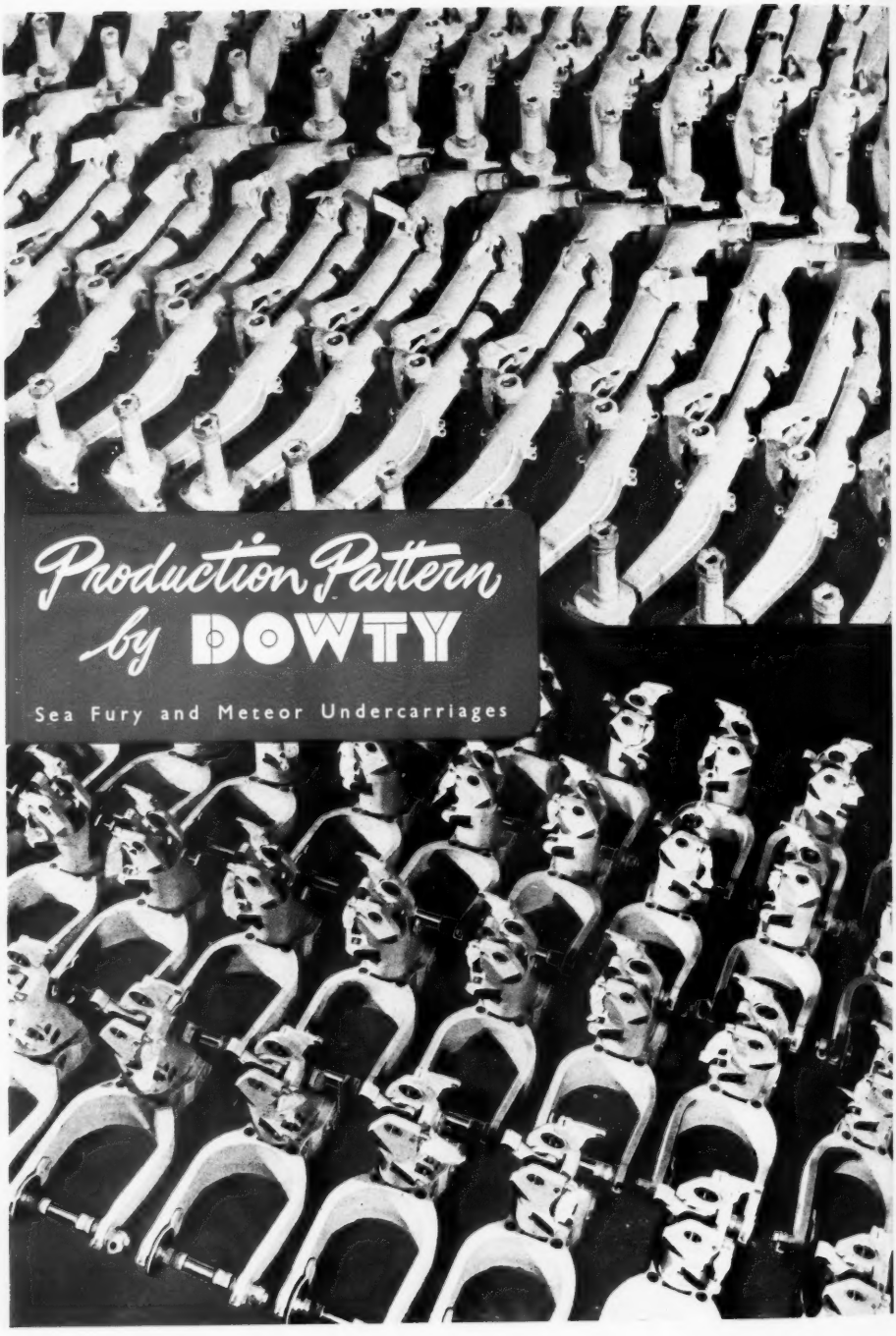
LONDON
ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, W.1


Production Pattern
by DOWTY
Sea Fury and Meteor Undercarriages

THE ROYAL AERONAUTICAL SOCIETY

GRADUATES' AND STUDENTS' SECTION

December 1950

SOME NOTES ON THE TERMS "g" AND "INERTIA"

By M. C. CAMPION, B.Sc.(Eng.), Grad.R.Ae.S.

PART III (*continued*)

(*Parts I and II were published with the August* JOURNAL *and the first sections of Part III with the October and November* JOURNALS)

III—*The loads on an aeroplane, and the resulting inertia factors* (*continued*)

(Paragraphs (*i*) and (*ii*) defined the notation used and paragraphs (*iii*)-(*viii*) described the vertical and fore-and-aft loads occurring in flight.)

(*ix*) Side loads in flight may be due to yawed flight or sideslip or horizontal (sideways) gusts. The loads applied to the aircraft are:

P_F the side load on the fin and rudder,

P_S the side load on the remainder of the aircraft,

M_F the yawing moment of P_F about the aerodynamic centre of the fin and rudder,

M_Y the yawing moment of P_S about the centre of gravity of the aircraft.

These loads cause a sideways (linear) acceleration, m "g's," a yawing acceleration, β "g's/foot," and a rolling acceleration, γ "g's/foot," about the centre of gravity, G.

The total side load on the aircraft is reacted by an equal and opposite sideways inertia force,

$$mW = P_F + P_S \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

and the yawing and rolling moments are reacted by equal and opposite inertia moments,

$$\beta I_Y = M_Y - P_F l_F + M_F \quad . \quad . \quad . \quad . \quad . \quad (23)$$

$$\gamma I_R = M'_R + P_F h_F \quad . \quad . \quad . \quad . \quad . \quad (24)$$

where l_F and h_F are the arms of P_F about the vertical and horizontal axes through G,

M'_R is the rolling moment, about G, of the pressure distribution on the wings, fuselage and tailplane.

The inertia factors are m (sideways), β (yawing) and γ (rolling) and act in the opposite senses to the actual accelerations of the aircraft.

The effect of the yawing inertia factor can be represented by increments in the sideways factor on the fuselage, and in the forward or aft factor on the wings. The effect of the rolling inertia factor can be represented by increments in the vertical factor on the wings; its effect on the fuselage can usually be neglected. The increments for any point can be found by the method described in paragraph (*vii*) of Part II.

(*x*) *Landing cases*:

It is impossible to represent exactly the worst landing loads in a limited number of real cases, but certain arbitrary combinations of vertical, drag and side loads have been found by experience to cover the load systems likely to occur in practice. These are specified in the handbooks of strength calculations (*see* second footnote to paragraph (*ii*), of Part III, October 1950 JOURNAL).

The basic cases may be considered to be:

(*a*) Landing on the main wheels only, with the maximum vertical load, either with or without drag or side loads. It is sometimes specified that when

the drag load has a certain value, the pitching acceleration of the aircraft shall be zero.

(*b*) Landing on the main wheels only, with a reduced vertical load, but a greater drag load than in (*a*).

(*c*) Landing on one main wheel only, with specified vertical, drag and side loads.

(*d*) A case similar to (*a*) but with all wheels in contact with the ground.

(*e*) A case similar to (*b*) but with all wheels in contact with the ground.

Cases (*a*) and (*d*) represent the conditions at some interval after touching down, when the maximum shock absorber travel has been achieved and the maximum vertical load developed. The drag loads are those due to rolling friction or an uneven surface. The side loads are due to uneven ground or to landing with drift.

Cases (*b*) and (*e*) represent the conditions occurring at the instant of touching down. The shock absorber travel is small and the maximum vertical reaction not yet developed. The drag loads, on the other hand, will be great, since the wheels have to be "spun up" until they are running freely with a peripheral velocity equal to the landing speed.

In all these cases ("airborne landing cases"), the aircraft is assumed to have no vertical or pitching acceleration at the instant before touching down, and the air loads will satisfy equations (9) and (10).

Suppose the aircraft to have a nose wheel undercarriage, and to be making an airborne three-point landing with drag and side loads. The six equations of instantaneous equilibrium can be obtained by resolving vertically, horizontally sideways and horizontally fore-and-aft, and by taking moments about the corresponding axes through the centre of gravity, G. In the notation of Figs. (*i*) and (*ii*) (October 1950 JOURNAL):

$$\left.\begin{aligned} nW &= L_W + L_T + R_M + R_N \\ mW &= S_M + S_N \\ dW &= D_M + D_N \\ \beta I_Y &= S_M l_M - S_N l_N \\ \alpha I_P &= M_0 + L_W (h - h_0)\bar{c} + M_T - L_T l_T - R_M l_M + R_N l_N - D_M h_M - D_N h_N \\ \gamma I_R &= S_M h'_M + S_N h'_N \end{aligned}\right\} \quad (25)$$

where h'_M, h'_N are the arms about G of S_M and S_N, measured vertically. Using equations (9) and (10), the first and fifth of equations (25) can be written

$$\left.\begin{aligned} nW &= W + R_M + R_N \\ \alpha I_P &= -R_M l_M + R_N l_N - D_M h_M - D_N h_N \end{aligned}\right\} \quad (26)$$

The wheel loads can be calculated from the information in the strength requirements, and with these and the appropriate dimensions, the right-hand sides of equations (25) and (26) are known. Hence the inertia loads and moments, which are given by the expressions on the left-hand sides of the equations, can be determined. The six inertia factors, m, n, d, β, α and γ, are known therefore and are equal and opposite to the actual accelerations of the aircraft. The resultant linear factors for any point on the aircraft can be obtained by combining the linear factors with the linear (tangential) components of the angular factors.

(*xi*) Take-off and taxi-ing cases are treated in the same manner as the landing cases, but the aircraft is assumed "non-airborne", all air loads being neglected.

(*xii*) In both the landing and take-off cases, the attitude of the aircraft can affect the loads considerably, since the centre of gravity is usually close to the main wheels. Equations (25) and (26) apply only when the datum line is horizontal, and must be modified accordingly if this is inclined to the horizontal.

(*To be continued*)

THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

NOTICES DECEMBER 1950

CHRISTMAS 1950

The President, Major G. P. Bulman, the Council and the staff of the Society wish all members, at home and overseas, a happy Christmas, and a happy and prosperous New Year.

CHRISTMAS HOLIDAYS

The Library and Offices of the Society will be closed from 5 p.m. on Friday, 22nd December, until Wednesday, 27th December, at 9 a.m.

NEWS OF BRANCHES AND DIVISIONS

The President, Major G. P. Bulman, has visited the Branches of the Society as follows:—

Wednesday, 4th October 1950	—	Annual Dinner of the Isle of Wight Branch. The Secretary and a number of members from London also attended.
Wednesday, 29th November 1950	—	Branch Lecture by Mr. W. H. Lindsey, M.A., F.R.Ae.S., on "The Control of Direct Coupled Gas Turbine Propeller Engines" at Southampton.

A Main Lecture of the Society was held at Belfast on Tuesday, 7th November 1950 when Major P. L. Teed, F.R.Ae.S., lectured on "Aircraft Metallic Materials Under Low Temperature Conditions". The President and Secretary attended with other members of the Society from London. The Lecture was followed by a Dinner organised by the Belfast Branch.

Prof. A. V. Stephens, Fellow, Chairman of the Australian Division, is in this country for a few months. His address is: St. John's College, Cambridge.

PAYMENT OF MEMBERSHIP SUBSCRIPTIONS UNDER DEEDS OF COVENANT

The Honorary Treasurer, Mr. C. F. Uwins, wishes to place on record his sincere appreciation of the very satisfactory response to the letter he recently sent to home Fellow, Associate Fellow and Companion members about payment of membership subscriptions under Deeds of Covenant.

MEMBERS NEW APPOINTMENTS

Mr. E. W. Coates, *Assoc. Fellow*—Design Staff of The Bristol Aeroplane Co. Ltd. (Aircraft Division), Filton, Bristol.

Mr. F. F. Crocombe, *Fellow*—Chief Engineer, Boulton Paul Aircraft Ltd.

Lord Hives, C.H., M.B.E., D.Sc., *Fellow*—Chairman of Rolls-Royce Ltd.

Mr. W. H. Lindsey, M.A., *Fellow*—Chief Engineer, Armstrong Siddeley Motors Ltd.

Prof. E. J. Richards, *Assoc. Fellow*—Chair of Aeronautical Engineering, University College, Southampton.

Dr. E. W. Still, *Fellow*—Research and Development Manager, Teddington Controls Ltd.

Mr. J. A. Tickell, *Assoc. Fellow*—Senior Assistant, Regent Street Polytechnic.

Mr. E. W. C. Wilkins, *Fellow*—Chair of Aeronautical Engineering at Cairo, Egypt.

Mr. H. M. Woodhams, C.B.E., *Fellow*—Managing Director, Sir W. G. Armstrong Whitworth Aircraft Ltd.

The Honorary Treasurer would also like to give a reminder to those members who intend to adopt his proposal but who have not yet returned their Deeds of Covenant.

The Secretary will be glad to send details of the scheme to any member who has not received the Honorary Treasurer's letter.

CONTENTS OF DECEMBER JOURNAL

The Third Louis Bleriot Lecture—Towards Slower and Safer Flying, Improved Take-Off and Landing, and Cheaper Airports, Sir Frederick Handley Page, C.B.E., Hon.F.R.Ae.S.

The Design Approximation of Skin Thickness From Stiffness Criteria, A. H. Hall.

Aircraft Riveting, H. Giddings, A.F.R.Ae.S.

Summary of the Activities of the Society in 1950.

Review. Index to Volume LIV, 1950.

The Council are particularly anxious to encourage members of the Society to support their own Journal by contributions to it of articles and papers on any aspect of Aeronautics. For that purpose they have set aside £250 a year in the form of premium awards to the authors (members or non-members) of such papers as some reimbursement for the work which has been done by the author. These premium awards are not fixed but vary from five to twenty guineas normally. It is hoped therefore that those members who have written papers on their special subjects will consider their own Journal in the first place.

THE AERONAUTICAL QUARTERLY—PART III, VOLUME II

Part III, Volume II of "The Aeronautical Quarterly" is now available from the offices of the Society at 7s. 9d. a copy to members of the Society, post-paid, or 10s. 3d. to non-members, post-paid.

The Contents of Part III are:—

Beams on Elastic Supports and on Cross-Girders ...	J. M. Klitchieff
The Estimation of Range of Jet-Propelled Aircraft ...	H. Pearson
On Non-Steady Motion of Slender Bodies	John W. Miles
The Correction of Wind Tunnel Nozzles for Two-Dimensional Supersonic Flow	R. E. Meyer and M. Holt
Some Developments of Expansion Methods for Solving the Flutter Equations	John Williams

The Contents of Part II, Volume II, copies of which are still available are:—

Critical Mach Numbers for Swept-Back Wings	S. Neumark
General Performance Reduction Equations for Reciprocating-Engined Aircraft with Constant-Speed Propellers ...	W. J. Annand
The Axially-Symmetrical Supersonic Flow Near the Centre of an Expansion	N. H. Johannesen and R. E. Meyer
Note on the Dependence of Flap Hinge Moment Derivatives on Hinge Position	W. J. Duncan
On the Chordwise Lift Distribution at the Centre of Swept Wings	D. Küchemann and J. Weber

Amendments to: "A Note on the Bending Moment Induced in the Booms of a Spar at the point of Application of a Concentrated Load" (Volume I Part IV) ... H. F. Winny

A few copies of Parts I to IV, Volume I and Part I Volume II are still available but members are reminded that a strictly limited edition only of "The Aeronautical Quarterly" is printed and numbers cannot be reprinted in any circumstances. An annual subscription therefore is advisable.

LOUIS BLERIOT LECTURE

The Fourth Louis Bleriot Lecture will be given in London by Monsieur Maurice Roy, Director, l'Office National d'Etudes et de Recherches Aéronautiques, on 23rd February 1951 on "Power Versus Weight in Aviation".

WILBUR WRIGHT MEMORIAL LECTURE

The Thirty-Ninth Wilbur Wright Memorial Lecture will be given before the Society in September 1951 by Mr. A. E. Raymond, Vice-President, Engineering, of the Douglas Aircraft Co. Inc., of California.

The title of the Lecture and the date will be announced as soon as possible.

NEWS OF MEMBERS

Mr. C. G. Grey, who joined the Society in 1909 and celebrated his 75th birthday on 13th November 1950, was recently elected an Honorary Life Member of the Royal Aero Club. The Society elected him an *Hon. Companion* earlier this year.

Dr. Theodore von Kármán, F.R.S., *Hon. Fellow*, has been awarded the Kelvin Gold Medal for 1950 in recognition of the eminent services he has rendered to engineering science.

Mr. Grover Loening, *Fellow*, has been awarded the Wright Brothers' Memorial Trophy for significant public service to Aviation in the United States.

Air Commodore Sir Frank Whittle, K.B.E., C.B., C.B.E., D.Sc., F.R.S., *Fellow*, has been awarded the Rumford Medal by the Royal Society for his pioneering contribution to jet propulsion of aircraft.

LIAISON WITH OTHER SOCIETIES

The following representatives of the Society have been appointed recently:

Mr. C. H. Jackson, *Assoc. Fellow*, to serve on the Committee on Radio Equipment for Civil Aircraft of the Institution of Electrical Engineers.

Mr. C. G. A. Woodford, *Assoc. Fellow*, to serve on the Committee on Regulations for Electrical Equipment of Aircraft of the Institution of Electrical Engineers.

Mr. B. A. Shenstone, *Fellow*, to serve on the City and Guilds of London Institute's Advisory Committee on Aeronautical Engineering Practice.

THIRD ANGLO-AMERICAN AERONAUTICAL CONFERENCE—1951

The Third Anglo-American Aeronautical Conference, convened jointly by the Royal Aeronautical Society and the Institute of the Aeronautical Sciences (of America), will be held at Brighton, Sussex, from 6th to 11th September 1951.

Previous Conferences have been held in London in 1947 and in New York in 1949.

Further information will be issued with the January JOURNAL.

COMMITTEE MEETINGS IN NOVEMBER

A meeting of the Council was held in the offices of the Society on 30th November 1950. Among the items discussed were the reports of the following Committees:—Finance Committee; Education and Examinations Committee; Branches Committee and Grading Committee.

During November five meetings were held by Committees of the Society. Outside bodies engaged in aircraft engineering and research held 16 meetings in the offices of the Society.

ANNUAL SUBSCRIPTIONS

Members are reminded that their annual subscriptions become due on 1st January 1951. The rates are:—

	Home	Abroad
	£ s. d.	£ s. d.
Fellows	5 5 0	4 4 0
Assoc. Fellows	4 4 0	3 3 0
*Associates	3 3 0	3 3 0
Graduates (aged under 26) ...	2 2 0	2 2 0
Graduates (aged 26 and over) ...	2 12 6	2 12 6
Students (aged under 21) ...	1 1 0	1 1 0
Students (aged 21 and over) ...	1 11 6	1 11 6
Companions	3 3 0	3 3 0
Founder Members	2 2 0	2 2 0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the JOURNAL, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership.

Remittances should be made payable to the Royal Aeronautical Society.

ELLIOTT MEMORIAL PRIZE

The Elliott Memorial Prize has been awarded to Leading Aircraft Apprentice 584592 Boyle, D., F. II. A., who obtained the highest marks in the General Studies Examination of the January 1948 Entry.

It will be presented at Passing-Out Prize Giving on 19th December 1950.

SPITFIRE MITCHELL SCHOLARSHIPS, UNIVERSITY COLLEGE, SOUTHAMPTON

A number of scholarships will be awarded to candidates with Industrial Experience for a course of study from Matriculation or preferably Intermediate standard to the External B.Sc. Engineering Degree of London University. The scholarships will be held at University College, Southampton, and will be tenable for three years. Candidates must be over 17 years of age. There is no upper age limit. Official forms can be obtained from the Academic Registrar, University College, Southampton, and must be returned completed not later than 20th December 1950.

ASSOCIATE FELLOWSHIP EXAMINATION—DECEMBER 1950

The next Associate Fellowship examination will be held on 18th, 19th and 20th December in the offices of the Society. The Library will be closed to members on those days. All candidates have been sent a time table and full particulars of the examination.

ASSOCIATE FELLOWSHIP EXAMINATION—AUGUST 1950

The following candidates were successful in their final subjects in the Associate Fellowship Examination held in August 1950 under the old syllabus:—

P. P. Benham, B. Buss.
J. A. Caister.
I. J. Davies.

R. W. Edwards, P. P. Elliott.
E. Fryer.
B. M. Goldsmith, F. Gowens, A. W. Gray, E. A. Greenwood.
R. N. Hadcock, W. E. Hagan (Montreal), S. D. Hall, J. T. Hawken, T. H. J. Heffernan, D. H. Hughes, J. H. Hurford.
F/Lt. F. A. Johnson, Cpl. W. G. Johnson (Ceylon).
M. Kishor, R. G. Knight, J. A. Kozlowski.
R. H. Ladd, W. W. Lewis, J. M. Lewendon, Sgt. P. Long (M.E.F.).
J. E. Mack, H. J. F. Manners, C. H. Martin.
J. Nash, D. Naylor, Miss J. M. Nelmes, N. N. Nicholls.
A. M. G. Olsen, J. L. O'Reilly (Nigeria).
B. G. Cour-Palais, C. S. Patro (Bangalore), J. W. Paulsen (Norway), R. G. Prasad.
C. Rajagopal (Bangalore), H. N. Roy.
A. J. Salmon, R. L. Samuels, D. Shellard, L. J. A. Sice, B. Singh (Nagpur), F/Sgt. N. V. Slatter (Malaya), F. M. Soonawalla, G. N. Srivastava.
T. V. Trinder (S. Africa).
E. Vezyrianidis.
D. W. Warne, K. R. Warren, C. R. J. Whitfield, K. F. Wood, J. Wyatt.

LECTURES

MAIN LECTURES

(At 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, London, S.W.1, unless otherwise stated. Tea will be served at 5.30 p.m.)

Thursday, 14th December 1950—Clear Air Turbulence Over Europe, Dr. G. S. Hislop, B.Sc., A.R.T.C., M.I.Mech.E., A.F.R.Ae.S.

Thursday, 15th February 1951—AT COVENTRY—Some Aspects of Flight Research, Handel Davies, F.R.Ae.S.—*at Siblee Hall, Coventry, at* 7.30 *p.m.*

GRADUATES' AND STUDENTS' LECTURE

(At 7.30 *p.m. in the Library of the Royal Aeronautical Society,* 4 *Hamilton Place, W.*1, *unless otherwise stated. Visitors are welcome to attend.)*

Tuesday, 12th December 1950—Film Show, by W. Courtenay, O.B.E., M.M., A.R.Ae.S.

BRANCH LECTURES AND NOTICES

Notices of Branch Lectures and Meetings for inclusion in the Monthly Notices of the Society must be received by the 20th of the preceding month. The Honorary Secretaries of all Branches are asked to inform the Society of their arrangements for meetings so that a complete list of Branch meetings may be given.

BELFAST BRANCH

Tuesday, 12th December 1950—Boundary Layer at High Speeds, Prof. A. D. Young, M.A., A.F.Ae.S.
Tuesday, 16th January 1951—Recent Developments in Landing Gear and Equipment, H. G. Conway, M.A., F.R.Ae.S.
Tuesday, 27th February 1951—Aircraft Carriers—Problems Associated with the Operation of Aircraft, J. L. Bartlett.
Tuesday, 13th March 1951—Radar—How it Works, B. W. Hodlin, B.Sc.(Hons.).
Tuesday, 3rd April 1951—Annual General Meeting.
In the Central Hall, College of Technology, Belfast, at 7 p.m.

BIRMINGHAM BRANCH

Friday, 15th December 1950—Radar and Kindred Pilot Aids.
At the Chamber of Commerce, Birmingham, at 7.30 p.m.
Friday, 26th January 1951—*Visit* to Goodyear Tyre Co. Ltd.

Friday, 30th March 1951—Flying The Brabazon, W. Pegg.
At the Chamber of Commerce, Birmingham, 7.30 p.m.

Friday, 27th April 1951—Annual General Meeting.
At White Horse Hotel, Birmingham.

BRISTOL BRANCH

Monday, 8th January 1951—Aircraft and Aero-Engine Vibrations, M. O. W. Wolfe, D.I.C. (Section Lecture.)

Monday, 15th January 1951—The Development of the Comet, R. E. Bishop, C.B.E., F.R.Ae.S.

Tuesday, 30th January 1951—The Aerodynamic Oscillation of Suspension Bridges. R. A. Frazer, D.Sc., F.R.Ae.S., F.I.Ae.S.

Wednesday, 14th February 1951—Civil Engineering and Aeronautics, A. G. Pugsley, O.B.E., D.Sc., F.R.Ae.S.

Tuesday, 27th February 1951—Human Factors in the Design and Operation of Civil Air Transport Aircraft, Kenneth G. Bergin, M.A., M.D., D.P.H., A.F.R.Ae.S.

Monday, 12th March 1951—Junior Members' Papers Competition.

Wednesday, 4th April 1951—Power Plant Requirements for Future Aircraft, S. G. Hooker, O.B.E., A.R.C.Sc., B.Sc., D.I.C., D.Phil., F.R.Ae.S., F.R.S.A.

Tuesday, 17th April 1951—Some Notes on Overhaul and Maintenance, C. H. Jackson, B.Sc., A.C.G.I., A.F.R.Ae.S., A.M.I.Mech.E.

Monday, 30th April 1951—Annual General Meeting and Film Show.

In the Conference Room, Filton House, The Bristol Aeroplane Co. Ltd. at 6 p.m. unless otherwise stated.

BROUGH BRANCH

Wednesday, 10th January 1951—Problems of High-Speed Flight, H. Davies, M.Sc., F.R.Ae.S.

Wednesday, 14th February 1951—A Talk on Aero-Engines, Air Commodore F. R. Banks, C.B., O.B.E., F.R.Ae.S.

Wednesday, 14th March 1951—Aircraft Structures, P. B. Walker, M.A., Ph.D., F.R.Ae.S.

In the Lecture Hall, Electricity Showrooms, Ferensway, Hull, at 7.30 p.m. Admission is by ticket only.

COVENTRY BRANCH

Wednesday, 13th December 1950—Films.

Wednesday, 21st February 1951—25th Anniversary Lecture (Main Lecture of the R.Ae.S.)—Some Aspects of Flight Research, Handel Davies, F.R.Ae.S.—*at Siblee Hall at 7.30 p.m.*

Wednesday, 18th April 1951—A.G.M. & Films.

In the Wine Lodge Hotel, The Burges, Coventry, at 7.30 p.m.

DERBY BRANCH

Monday, 1st January 1951—The Design Requirements of Naval Aircraft, Lt. Cdr. (A) E. M. Brown, O.B.E., D.S.C., A.F.C., M.A., A.F.R.Ae.S.

Monday, 5th February 1951—Pressurising and Cabin Air Conditioning, W. M. Widgery, F.R.Ae.S.

Monday, 12th March 1951—The Cierva Air Horse, J. S. Shapiro, Dipl. Ing., A.F.R.Ae.S.

Monday, 2nd April 1951—The Evolution of the Design of a Jet Engine, A. A. Lombard, A.F.R.Ae.S.

Monday, 7th May 1951—Long Range Turbo-Jet Transport, A. E. Russell, B.Sc., F.R.Ae.S.

In the Rolls-Royce Welfare Hall, Nightingale Road, Derby, at 6.15 p.m.

GLASGOW BRANCH

Friday, 15th December 1950—Annual General Meeting.
February 1951—Thin Walled Structures, Dr. Kennedi.

At St. Enoch Hotel, Glasgow, at 7.30 p.m.

ISLE OF WIGHT BRANCH

Wednesday, 13th December 1950—Annual General Meeting and How the Birds Learnt to Fly, R. E. F. Potter.
Thursday, 11th January 1951—The Cierva Air Horse, J. S. Shapiro, Dipl. Ing., A.F.R.Ae.S.
Thursday, 25th January 1951—Economic Aspects of Civil Aviation, P. Masefield, M.A., F.R.Ae.S.
Thursday, 22nd February 1951—Interplanetary Flight—(The Rocket Engineer's Point of View), A. V. Cleaver, A.R.Ae.S. (This Lecture is complementary to that given on 1st November 1950.)
Thursday, 8th March 1951—Methods of Time Keeping, Dr. R. d'E. Atkinson.
Thursday, 22nd March 1951—Junior Branch Prize Lecture.

LEICESTER BRANCH

Wednesday, 13th December 1950—Research in Civil Aviation, N. E. Rowe, C.B.E., B.Sc., F.R.Ae.S.
Wednesday, 24th January 1951—Annual General Meeting and Films.
Wednesday, 21st February 1951—Welded Magnesium Aircraft Structures, R. J. Cross.
Wednesday, 7th March 1951—The Island Campaign (Coloured Film), W. Courtenay, M.M., A.R.Ae.S.
Friday, 13th April 1951—Rockets and Space Travel, J. Humphries.

In Room 104, College of Technology, The Newarkes, Leicester, at 7.15 p.m.

MANCHESTER BRANCH

Wednesday, 20th December 1950—A.I.D. Methods of Testing, W. N. Backlock. A.F.R.Ae.S.
Thursday, 25th January 1951—The Viscount Turbo-Prop. Aircraft, G. R. Edwards, M.B.E., B.Sc., F.R.Ae.S.
Wednesday, 28th February 1951—Film: Steelmaking and Usages. (Thos Firth & John Brown Ltd. and Firth-Vickers Stainless Steels Ltd.).
Thursday, 29th March 1951—Cabin Air Conditioning, W. M. Widgery, F.R.Ae.S.

In the Reynolds Hall, College of Technology, Manchester, at 7.30 p.m.

PORTSMOUTH BRANCH—FILM PROGRAMME

Thursday, 14th December 1950—Oxy-Acetylene Welding (British Oxygen Co.).
Thursday, 4th January 1951—Woodscrews to Wagon Wheels, (Guest, Keen & Nettlefold).
Thursday, 18th January 1951—Plastics, (De la Rue Insulation Ltd. & Bakelite Ltd.).
Thursday, 1st February 1951—Stainless Steels (Firth Vickers Stainless Steels Ltd.).
Thursday, 15th February 1951—'Pluto' and Welded Structure' (Stewarts & Lloyds and Dorman, Long & Co. Ltd.).
Thursday, 1st March 1951—Wood (CFL Films, & Aims of Industry Film).
Thursday, 15th March 1951—Casting & Forging Light Alloys (High Duty Alloys).
Thursday, 29th March 1951—Annual General Meeting.

At the Apprentices' School, Airspeed Ltd., The Airport, Portsmouth, at 6 p.m.

SOUTHAMPTON BRANCH

Wednesday, 17th January 1951—Film Show.
Wednesday, 21st February 1951—Aircraft Undercarriages, R. C. Cussons, M.A.
Wednesday, 21st March 1951—The Further Development of the Brabazon Type, G. P. Hebden, B.Sc., A.F.R.Ae.S.
Wednesday, 11th April 1951—Instrumentation for testing Aircraft and Aero-engines, C. Jaques. (Joint meeting with Southern Branches of Institution of Mechanical Engineers and Institution of Electrical Engineers).

In the Physics Lecture Theatre, University College, at 7 p.m.

WEYBRIDGE BRANCH

Wednesday, 13th December 1950—Designing for High Speed, Professor E. J. Richards, M.A., B.Sc., F.R.Ae.S.
Friday, 29th December 1950—Annual Dance.
Wednesday, 10th January 1951—High Speed Flight, S/Ldr. J. D. Derry, D.F.C.
Wednesday, 31st January 1951—The Life and Work of Col. S. F. Cody, G. A. Broomfield.
Wednesday, 21st February 1951—Some Problems of Air Interception, Air Vice Marshal T. G. Pike, C.B., C.B.E., D.F.C.
Wednesday, 14th March 1951—Turbine-Engined Aircraft, G. R. Edwards, M.B.E., B.Sc., F.R.Ae.S., A.M.I.Strut.E.
Wednesday, 4th April 1951—Gas Turbines, Dr. S. G. Hooker, O.B.E., A.R.C.Sc. B.Sc., D.I.C., D.Phil., F.R.Ae.S., F.R.S.A.
Wednesday, 18th April 1951—Junior Prize Lecture, Branch Members.
Wednesday, 2nd May 1951—Annual General Meeting and Smoking Concert.

At Vickers-Armstrongs Ltd., Weybridge, at 6 p.m.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

William Alexander Beedie (from Student), Raymond Percy Bonham, Kenneth Arthur Joseph Foord (from Graduate), Samuel Paul Johnston, Robert Maximilian Kenedi, Henry Morgan, Kenneth Raymond Nuttall (from Graduate), Colin Winterbotham Weedon, Derek Victor Wordsworth (ex-Assoc. Fellow).

Associates

Henry Horace Cadman, Maurice Reginald Chantrill, Ronald Evans, William James Flake, George Joseph McTigue, Leslie Roberts, Frederick William Sainsbury, Harold West, James Winward, Peter Alan Woolf.

Graduates

Josef Aretz (from Student), Percy Geoffrey Ball (from Student), Antony Chinneck, John Grigor, Ronald Charles Harris (from Student), Stephen John Taylor Harvey (from Student), David Arundel Yeo O'Clarey (from Student), Edmund Archdale Palmer, John Norman Quick, Geoffrey Cowie Sugden (from Student), Francis Robert Ward.

Students

Bernard Arthur Bridges, Shin Lan Chan, Peter John Elmes, Derek Alexeis Horton, Eric Antony Robert Humpston, William Dennis Sproson, Peter Appleby Trotman, Robert Desmond Ward, Denis Edward Weeding, Patricia June Wilson.

Companions

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CIERVA MEMORIAL PRIZE

The closing date for entries for the Cierva Memorial Prize, awarded annually by the Helicopter Association of Great Britain, is the 31*st March* 1951, not 1950 as given in the November Notices.

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The following have been added to the Library (titles of pamphlets are printed in italics. Books marked * or ** may not be taken out on loan):—

Anderson, C. D.	Elementary Particles of Physics. Smithsonian Institution. 1949.
British European Airways Corporation	Report and Accounts, 1949-50. B.E.A. 1950.

*Bureau of Ordnance	Handbook of Supersonic Aerodynamics. NAVORD Report 1,488. U.S. Govt. Printing Office. 1950.
Freudenthal, A. M.	Inelastic Behaviour of Engineering Materials and Structures. John Wiley. 1950.
Hill, R.	Mathematical Theory of Plasticity. Oxford University Press. 1950.
McLachlan, N. W.	Ordinary Non-Linear Differential Equations. Oxford University Press. 1950.
Ministry of Civil Aviation	Consol: A Radio Aid to Navigation. H.M.S.O. 1950.
Pratt & Whitney	The Pratt & Whitney Aircraft Story. Pratt & Whitney. 1950.
Symonds, P. S.	Review of Methods for the Plastic Analysis of Rigid Frames of Ductile Metal. Brown University. 1950.

A.R.C. Current Papers

14—*Determination of the static stability of seaplanes. K. M. Tomaszewski.*
17—*Wind tunnel tests on a one-twelfth scale model of a twin-engined military transport (Airspeed C 13/45 Ayrshire). R. Warden.*
22.—*Preliminary measurements of the aerodynamic damping in pitch of a 12 ft. diameter helicopter rotor. C. M. Britland and R. A. Fail.*
23—*An electronic analyser for linear differential equations. J. J. Gait and D. W. Allen.*
24—*Porous properties of various materials liable to be used for making parachutes. W. D. Brown and J. F. Holford.*
25—*The effect of variation of air density and temperature on the airflow characteristics of porous fabrics. J. Picken.*
26—*The electronic simulator for the solution of flutter and vibration problems. F. Smith.*

A.R.C. Reports and Memoranda

2401—*Note on the increase of drag of an aerofoil due to the thickening of the boundary layer behind a shock wave. A. D. Young and Miss E. Young.*

Aeronautical Research Consultative Committee, Australia. Reports

ACA-44—*Structural efficiency of wings. J. Solvey.*
ACA-45—*The influence of wing geometry and structural efficiency on aircraft performance. J. Solvey.*
ACA-47—*Stability derivatives. The use of strain gauge balances in the measurement of velocity and control derivatives. P. T. Fink.*
ACA-48—*A review of some basic types of geometric stress concentration. D. A. Lemaire.*

Aeronautical Research Laboratories, Australia

Instruments Notes

49—*A stroboscope for the illumination of vibrating wings. H. M. Nelson and B. K. Barnett.*

Reports

*A.70—*Wind tunnel development and flight tests in Australia of a thick suction wing. Boundary Layer Control Group.*
SM.151—*An analysis of the response of a damped dynamical system subjected to impressed forces. R. W. Traill-Nash.*

Ministere de l'air, France, publications scientifiques et techniques

243—*Contribution a l'étude des diffuseurs en vue de l'application aux souffleries aérodynamiques subsoniques. R. Goethals.*

N.T.37—*Application précise d'une clause qualitative de régularité au dépouillement des courbes expérimentales et a la solution de certains problèmes mathématiques. P. Vernotte.*

N.T.38—*Note sur une représentation rectiligne des hyperboles sphériques. P. Hugon.*

Nationaal Luchtvaartlaboratorium, Holland, Reports in English

Systematic representation of aerodynamic coefficients of an oscillating aerofoil in two-dimensional incompressible flow. D. J. Hofsommer.

Kungl. Tekniska Högskolan—Institutionen för Flygteknik. Technical Notes in English

17—*Effect of geometric dihedral on low-speed static stability characteristics of a 40° swept-back wing. K. Orlick-Rückermann.*

18—*An approximate method for the determination of the increase of maximum lift on thin profiles due to trailing edge flaps. H. O. Palme and S. Stark.*

National Advisory Committee for Aeronautics, U.S.A.

Report

952—*Direct method of design and stress analysis of rotating disks with temperature gradient. S. S. Manson.*

**Technical Memoranda*

1268/9—*Isentropic phase changes in dissociating gases and the method of sound dispersion for the investigation of homogeneous gas reactions with very high speed. Volumes 1 and 2. G. Damköhler.*

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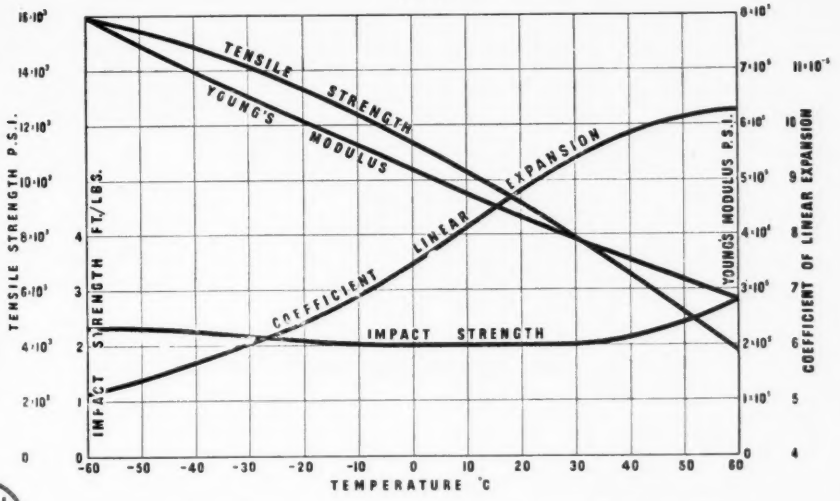

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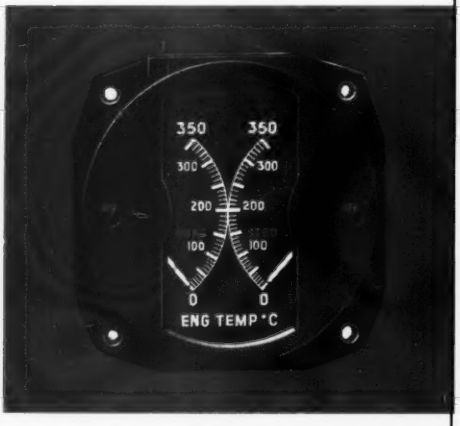

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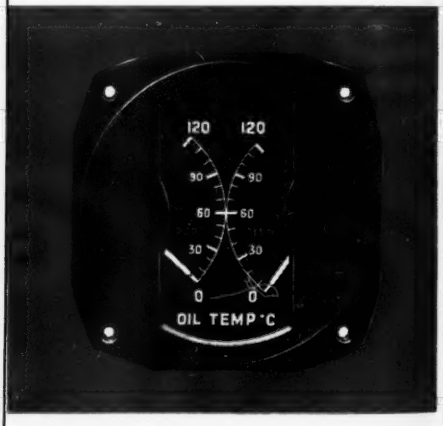

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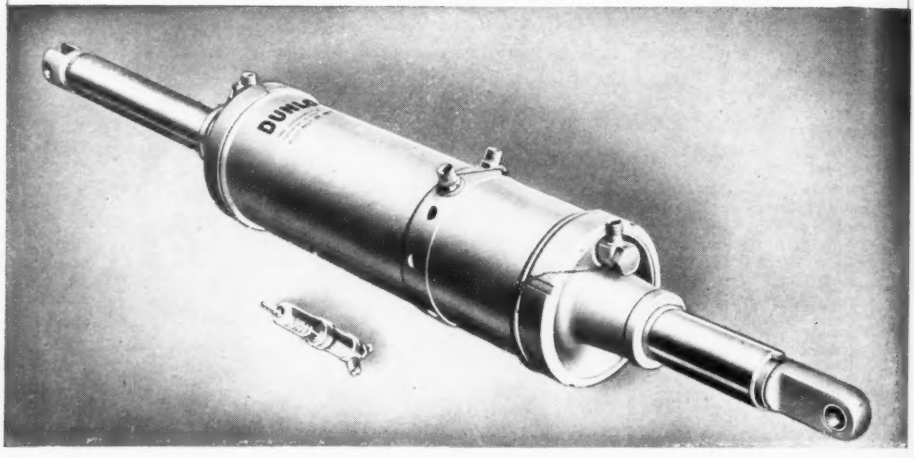

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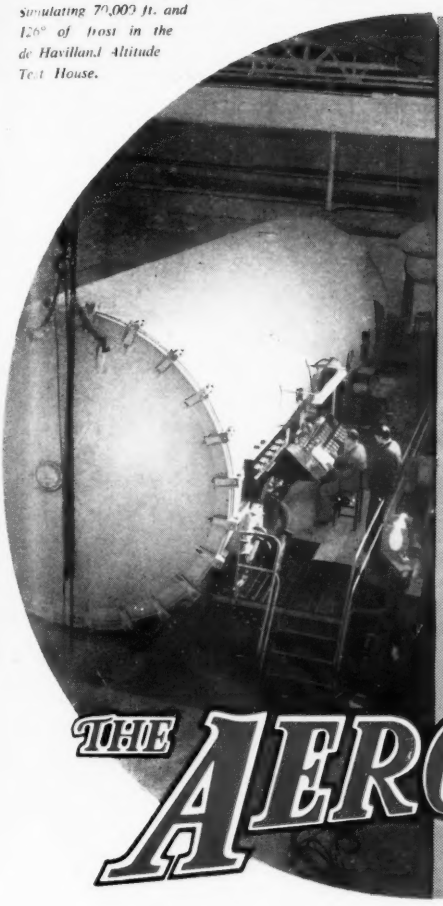

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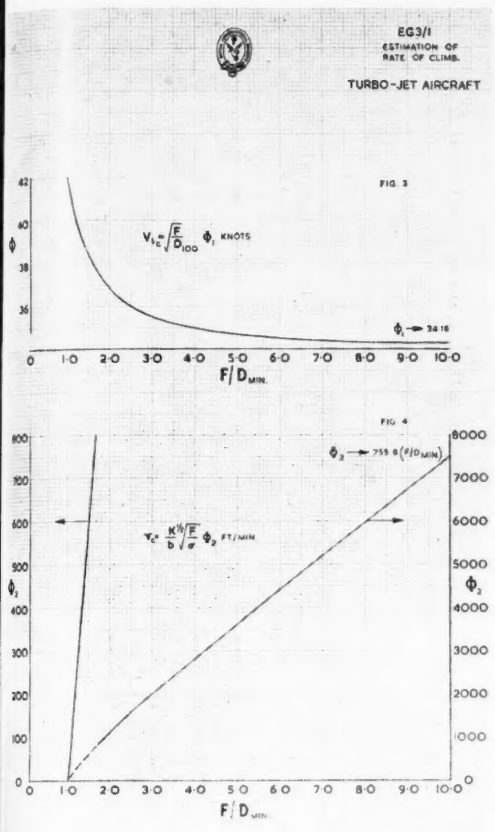

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THE THIRD LOUIS BLERIOT LECTURE

TOWARDS SLOWER AND SAFER FLYING, IMPROVED TAKE-OFF AND LANDING, AND CHEAPER AIRPORTS

by

SIR FREDERICK HANDLEY PAGE, C.B.E., Hon.F.R.Ae.S.

THE THIRD Louis Bleriot Lecture was given in Paris in the Conference Room of the Hotel George V on the 4th May 1950, under the auspices of the Association Française des Ingénieurs et Techniciens de l'Aéronautique, by Sir Frederick Handley Page, C.B.E., Hon.F.R.Ae.S., Past-President of the Society. The Lecture was read by Ingénieur en Chef Pierrat, of the Technical Aviation Service.

The Lecture was attended by Sir John S. Buchanan, O.B.E., F.R.Ae.S., President of the Society, by Mr. W. G. A. Perring, C.B., F.R.Ae.S., and Mr. N. E. Rowe, C.B.E., F.R.Ae.S., Vice-Presidents, and by Captain J. Laurence Pritchard, C.B.E., Hon.F.R.Ae.S., Hon.F.I.Ae.S., Secretary of the Society, as well as by a number of members of the Society and the British Aircraft Industry.

Monsieur Jules Jarry, President of A.F.I.T.A., presided at the meeting, introducing the Lecturer and welcoming the visitors. Later in a speech he commented on the changes which had taken place since their last meeting in London; the political horizon had darkened; the Atlantic Pact had been signed by the major democratic States and plans were being made for their common defence.

Because the Third Louis Bleriot Lecture was an occasion which marked Anglo-French solidarity and co-operation it was a fitting time to examine certain aspects of technical collaboration between them.

A strong Air Force to-day, up-to-date and complete, involved the creation by each country of about 50 models of aircraft and 20 to 30 varieties of engine. Nearly always these types had scarcely been developed and got into shape before a new technique appeared reducing the value of these types, if not making them obsolete. Because of this vast and changing programme there seemed to be an opportunity for co-operation on a big scale.

Why should the results of completed tests on prototypes not be given to partners in order to avoid costly duplication of effort and so that the possibility of development which might be profitable to them all be known? They all had the same problems in the field of research to-day and many countries had the same difficulties. In France they had no high-speed wind tunnels of variable density, but there were several in both the United States and Great Britain, and even in a small country such as Holland. Could not the models of associated countries be sent for testing in those tunnels? Could they not agree on a development programme for those great and costly means of research which were always changing and which created such financial difficulties for each country? There were many dispersions of effort in their existing systems which might be avoided by judicious co-operation.

The nations spoke of co-operation and assistance and he had suggested a plan for aeronautics. Those who believed in the primary role of aviation in national defence found another reason for urgency. There seemed to him to be no better time to speak of such things than at their re-union that day which was such an example of the collaboration between the two associations representing the aviation technicians of their two countries who were specially qualified to know the technical aspects and the investigations as a whole which were needed.

INTRODUCTION

To fly farther, to fly higher, and to fly faster, have been the aims ever urging the aircraft designer on to further progress. Of all, the lust for high speed is the most compelling. While the past few years have seen spectacular increases in the World's High Speed Record (*see* Fig. 1) still higher performance in the supersonic region will be commonplace in the near future. To attain these speeds, largely made possible by the increased power and light weight of the turbo-jet unit, the designer must seek out means still further to reduce aerodynamic drag.

Until now, drag has been reduced chiefly by making the wetted surface of the aeroplane as small and as clean as possible. This has led to smaller wings and increased wing loadings, has resulted in higher stalling speeds (unless special counter-action was taken) and, in consequence, to longer runs for take-off and landing.

In Table I and in Figs. 2 and 3 particulars given of the 1930 Hannibal used on the London-Paris service of Imperial Airways and the 1950 Hermes IV of B.O.A.C., indicate the way in which wing loadings have increased during the past 20 years. What is even more significant is to note how, due to these increased take-off and landing runs, airport facilities have had to be extended to make present civil aviation on international trunk lines possible. Throughout the world, whether for civil or military aircraft, it has tacitly been assumed that an increase in landing speed, caused by increased wing loading, could be tolerated and that, if necessary, runways would be lengthened to suit. Prior to World War II, runways, and certainly most municipal airports, were grass surfaced and seldom exceeded 3,000 ft. (900 m.) in length. The War, with its emphasis on the importance of air power, made possible the rapid creation and extension of runways, vast structures of hard core and concrete which hitherto would have been considered uneconomic and quite out of the question. It is now commonplace for even a small aerodrome to have in the runways the equivalent of 10 miles of first class 40 ft. wide roads.

TABLE I.

AIR LINER CHARACTERISTICS (1930-1950)

Item	*H.P. Hannibal Imperial Airways (London-Paris)* 1930	*H.P. Hermes IV B.O.A.C. (Empire Routes)* 1950
All-up weight (lb.)	28,500	82,000
Brake horsepower for take-off	4 × 550	4 × 1,938
Gross wing area (ft.²)	2,990(277m²)	1,408(130m²)
Span (ft.)	130 (39.7m)	113 (34.6m)
$C_{L\max}$ normal	1.13	1.35
$C_{L\max}$ flapped	——	1.87
Aspect ratio	8.55	9.06
Wing loading (lb./ft.²)	9.54 (46.5)	58.2 (294)
Power loading (lb./h.p.)	12.95 (5.98)	10.6 (4.88)
Take-off		
Ground run (yd.)	287	1,153
Total run to 50 ft. (yd.)	460	1,380
Landing		
Landing weight (lb.)	28,500	75,000
Total run from 50 ft. (yd.)	——	1,200
Ground run (yd.)	222	970
Speeds (Stalling)		
For take-off (m.p.h.)	57.5	110.5
Landing (m.p.h.)	57.5	105.8

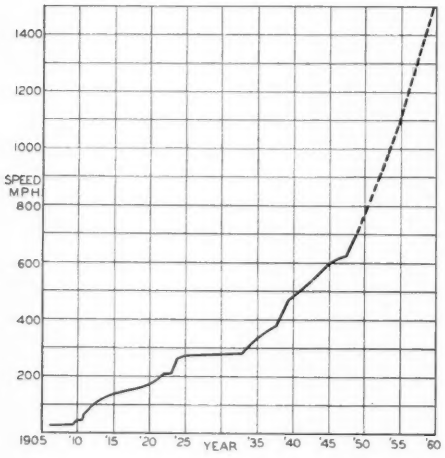

Fig. 1.

World speed records.

Table II gives a list of the costs of some well-known airports. Runways at London Airport and Filton (Bristol) are 10,000 ft. (3,000 m.) in length and some 300 ft. (90 m.) wide and cost about £1 million a runway. It is not surprising therefore that the capital cost of London Airport will amount to some £26 million. At Idlewild International Airport (New York) seven runways so far have been constructed, but it is doubtful if the

TABLE II.

COST OF AIRPORTS

		Date of assessment
London Airport	£26 million	1950
Idlewild (New York)	$110 million	Aug. 1949
Orly (Paris)	Fr.50 million	May 1948
Pistarini (Buenos Aires)	$210 million	June 1949
Sydney (Australia)	£5 million to 1st stage of 2 runways	Aug. 1949
Ciampino (Rome)	L.6,000 mill. 1st stage	Mar. 1948

extension scheme proposed will be put in hand at a later date. Washington National Airport (cost inclusive of current appropriations $25 million) is likely to be inadequate to cope with air traffic in 1955 and a new airport is planned for which the first single runway installation will cost $14 million (covering land purchase, building construction and an access road).

There is a limit to this big runway policy. Few countries are likely to be able to afford to extend many of their smaller runways, much less to build many airports to such a standard, for not only are they expensive in money, but the amount of land immobilised is unjustifiable. An easement of aerodrome landing strip facilities would be welcomed, it is believed, by everyone—including the poor taxpayer.

At some airports, extensions will prove to be physically impossible; and alternative sites, at others, will be so distant from the cities they are to serve, that aeroplanes *must* conform to present limitations or the cities will have to forego the advantages that civil air transportation can confer. Table III illustrates the airport facilities which have been provided for some of the most important cities in the United Kingdom.

While in civil air operations the installation of a first class runway may be impossible because of cost—particularly in some of the undeveloped areas—in military operations the need for a super long runway entails an immense expenditure of time and man power before an operation can be carried out. Thus air power is deprived of that flexibility in strategy which is so essential a characteristic.

This prodigal conception of runways has now to be countered. One of the main objects of this paper is to draw the attention of all concerned, operator, designer and not least, the airport authorities, to those mounting capital and upkeep costs which must eventually be borne as part of the price for air operations; and then to review those aircraft design developments which would lead towards a simplification of the basic problems of the airport and airline operators.

The case for a review of landing and take-off requirements having been established, it now remains to consider how the designer can reduce operating costs to airline operator and airport authority alike.

It may well come as a surprise that anyone connected with aviation, the chief characteristic of which is high speed, should advocate a change in the emphasis that is to be put on the speed range—that attention must be given to an extension of the lower end of the speed range. It will be the purpose of what follows to show that such an outlook is far from reactionary but, on the contrary, essential for the well-being of aviation in general and civil aviation in particular.

The operator should welcome lower landing and take-off speeds because they would provide additional safety. On days of poor visibility, the pilot of a slower aircraft would take fewer risks because, while his time for reaction to changing conditions is constant, the time interval to meet those emergencies is lengthened. If landing runs are reduced, a greater number of emergency landing grounds is available for use. It seems reasonable to suppose that with slower minimum

TABLE III.

PRINCIPAL AIRPORT FACILITIES IN THE UNITED KINGDOM

Town or City	*Airport*	*Length of main runways* *Feet*	*Metres*
	Prestwick	6,600	2,000
Glasgow	Renfrew	6,000	1,830
Belfast	Nutts Corner (12 miles distant)	6,000	1,830
Belfast	Sydenham	3,360	1,025
London	Northolt	5,250	1,600
Liverpool	Speke	5,000	1,520
Cardiff	Llandow (15 miles distant)	4,900	1,490
Cardiff	Pengam Moors	2,900	885
Birmingham	Elmdon	4,260	1,300
Manchester	Ringway	4,200	1,280
Isle of Man	Ronaldsway	4,200	1,280
Aberdeen	Dyce	4,000	1,220
Edinburgh	Turnhouse	3,990	1,220
Southampton	Eastleigh	3,900	1,190
Leeds	Yeadon	3,700	1,130
	Jersey	3,690	1,125
Nottingham	Tollerton	3,350	1,025
Newcastle	Woolsington	3,200	975

Fig. 2.
H.P. Hannibal 1930.

flying speeds, there would be a reduction in the use of alternative aerodromes when weather conditions are bad. This would improve block speeds, reduce the amount of non-productive flying time and, in turn, lead to better utilisation of a fleet of aircraft. Thus, without any increase in actual cruising speed, it is possible for the operator to achieve a higher block speed. This, after all, is what counts, especially as it leads to higher utilisation. Airport authorities, too, are interested in the effects that slower flying speeds must have on airport costs and requirements.

In general, as will be seen from Table IV, take-off distances of current air transport types are longer than landing distances. Much of the present investigation therefore is concerned with reduction of take-off runs, since the landing problem will also be looked after if minimum flying speeds are reduced.

The aerodynamic problems will be examined first—how wing-lift can be increased without an excessive increase in drag, so as to give shorter take-off runs; and then means will be reviewed for easing runway and undercarriage problems.

THE AERODYNAMIC PROBLEM.

1—Some theoretical considerations

The aerodynamic problem of increasing wing lift is one which has been dealt with exhaustively in theoretical work and by wind-tunnel tests and full-scale measurement.

The effect on aeroplane performance can be illustrated by the changes which result on the Hermes IV. If $C_{L\max}$ of the Hermes IV is increased progressively up to about 3.5 (*see* Fig. 4 and Table V) there is a substantial reduction in the total take-off run. Beyond this value further reduction up to $C_{L\max} = 5$ is not worth while. It will be noted that reduction in all-up weight gives much greater reduction in take-off run for low values of $C_{L\max}$ than for high values. This can be seen by comparing the take-off run in Fig. 4 for alternative weights of 85,000 lb. (38,600 kg.) and 75,000 lb. (34,000 kg.) respectively.

With increase in $C_{L\max}$ comes an increase in induced drag, not as a direct function of area, but of (span)^2. In consequence, as the maximum lift coefficient is increased and

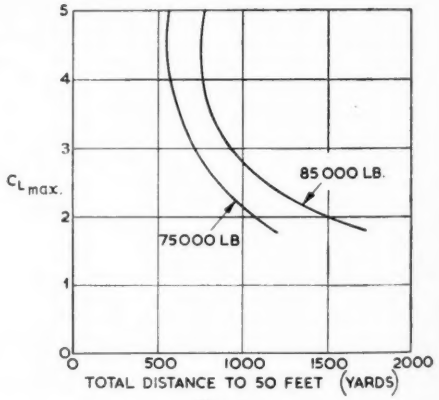

Fig. 4.
Hermes IV take-off distance as affected by $C_{L\max}$.

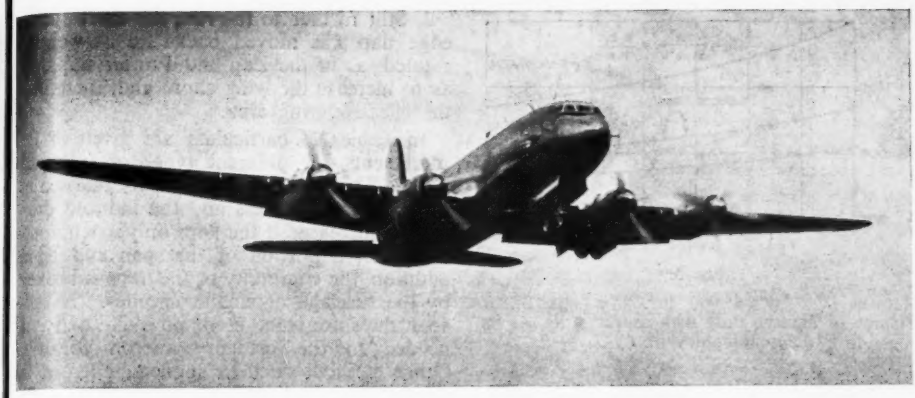

Fig. 3.
H.P. Hermes IV 1950.

minimum flying speed reduced, wing span must be increased to minimise the rise in induced drag. Accordingly, to maintain induced drag constant as C_L is increased, aspect ratio must be increased in like proportion. Fig. 5 shows the increasing significance of induced drag as minimum flying speed is reduced and also, how important it is to use high aspect ratio to avoid undue increase in induced drag. If the C_{Lmax} of the Hermes IV is increased from 1.8 to 2.8, but the wing loading is unaltered, the induced drag is kept unchanged only if the aspect ratio is increased from 9.06 to 14.2 (or the span from 113 ft. (34.4 m.) to 141.4 ft. (43 m.)). The aspect ratio required to maintain induced drag unchanged for higher values of C_{Lmax} would result in a structure of such a span that the increased weight would be prohibitive.

TABLE IV.

TAKE-OFF AND LANDING DATA FOR TRANSPORT AEROPLANES

Type	*Take-off Distance to 50 ft.*		*Landing Distance from 50 ft.*	
	yd.	*m.*	*yd.*	*m.*
Douglas DC-3	833	762	778	711
Douglas DC-4	1,450	1,327	1,050	960
Douglas DC-6	1,867	1,710	980	896
Lockheed Constellation 749	1,683	1,540	933	854
Boeing Stratocruiser 377	2,167	1,982	1,300	1,190
H.P. Hermes IV	1,380	1,262	1,200	1,098
Martin 2-0-2	1,317	1,205	800	732
Convair-Liner	1,317	1,205	788	720

(Data from *Shell Aviation News*, January 1950 — except Hermes IV, 82,000 lb.)

Thus, the question of increased C_{Lmax}, and at the same time increased aspect ratio, cannot be considered as an aerodynamic problem only, but must take into account the resulting increase in wing-structure weight.

Figure 6 shows how the estimated weight of Hermes wings of constant area increases with increase in span, it being assumed that the wing span root thickness ratio (b/t) and the all-up weight (85,000 lb. (38,600 kg.)) have been kept constant.

The actual weight of the Hermes wing, for aspect ratio 9.06, agrees fairly well with the formula

$$W_w = 0.046\, S\, A^{0.47}\, (W/b)^{0.53}\, (b/t)^{0.115} \text{ lb.}$$

Figure 6 shows that the increase in wing weight is 860 lb. (390 kg.) for an increase in aspect ratio from 9.06 to 14.2, the increase required to maintain induced drag constant for an increase of C_{Lmax} from 1.8 to 2.8. Unless, therefore, the all-up weight of the aircraft can be raised by something considerably in excess of 860 lb. (390 kg.) (to allow for changes in tail structure) the change is not worth while.

The importance of aspect ratio and allowable all-up weight on take-off becomes even more significant if the aeroplane is to be operated in the tropics at high altitudes, particularly with turbo-jet power units.

The problem which now remains to be studied is what type of lift-increasing device can be employed which will permit of lift coefficients up to, say, 3.5 without undue increase in wing drag or weight.

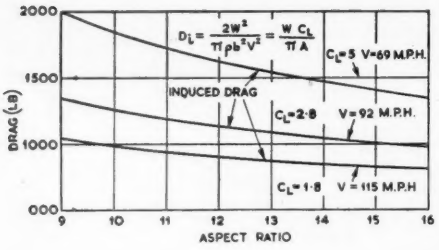

Fig. 5.

Hermes IV. $W = 85{,}000$ lb. $S = 1{,}408$ sq. ft. Change of induced drag with aspect ratio (A) for different values of C_{Lmax}.

2—Devices for Increasing Wing Lift

Broadly speaking, there are four ways to increase lift:—

1. By increasing the circulation around the wing by rotating a flap and thus increasing the wing camber.

2. By increasing wing area by a backward chordwise movement of a trailing-edge flap.

3. By preventing breakdown of the flow at the stall by means of slots and extending the angular range of incidence for useful lift.

4. By increasing the circulation over the wing by the application of forced boundary layer control.

1. The oldest method of increasing the circulation around a wing was by increasing the wing camber, either by warping the wing or rotating a flap downward. Later developments were the split flap and the H.P. slotted flap.

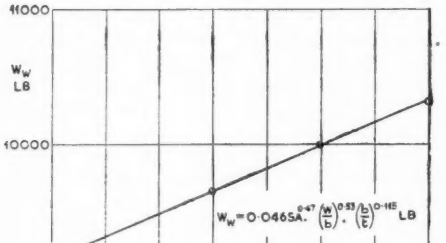

Fig. 6.

Wing weight as affected by aspect ratio.

2. Still further to increase lift the trailing-edge flap was moved backward as well as rotated, as in the Zap and Fowler flaps, so as to increase the wing chord and, therefore, the effective wing area.

In Table VI particulars are given of lift increments for different types of full-span flaps. The actual lift increments realised in full scale will be less and the induced drag will be increased if the flaps only extend outboard for a portion of the span and if, in addition, the continuity of the flaps is broken by the fuselage or engine nacelles. If full-span flaps are to be used some alternative is needed to the ordinary aileron controls. Other methods such as spoilers, ailerons in the flaps, and so on, have not proved to the general liking of pilots, so that if the full value of lift increment is to be obtained, an alternative and acceptable method must now be developed. It is equally necessary to ensure that the parasitic drag of the wing system is not unduly increased with increase in lift, otherwise the initial climb, whether with full power, or in the engine-cut case, will be very adversely affected.

A flap for low parasitic drag is shown in Fig. 7, together with the results of wind tunnel tests upon it. It will be seen that the form drag of the wing remains practically constant over a wide range of lift coefficients.

With trailing-edge flaps alone, actual C_{Lmax} seldom exceeds about 2.7.

3. Full-span leading-edge slots give still higher values of C_{Lmax} but require higher angles of incidence in landing.

TABLE V.

Effect of C_{Lmax} on Total Distance for Take-off of Four-engined Civil Air Transports of Hermes Class

C_{Lmax}	*Total distance (yd.) for take-off to 50 ft.*	*Reduction in total distance in yd. per* $\Delta C_L = 0.2$
1.8	1,725	—
2.0	1,485	240
2.2	1,310	170
2.4	1,185	125
2.6	1,080	105
2.8	992	88
3.0	920	72
3.2	868	52
3.4	827	41
3.6	795	32
4.0	760	—
5.0	771	—

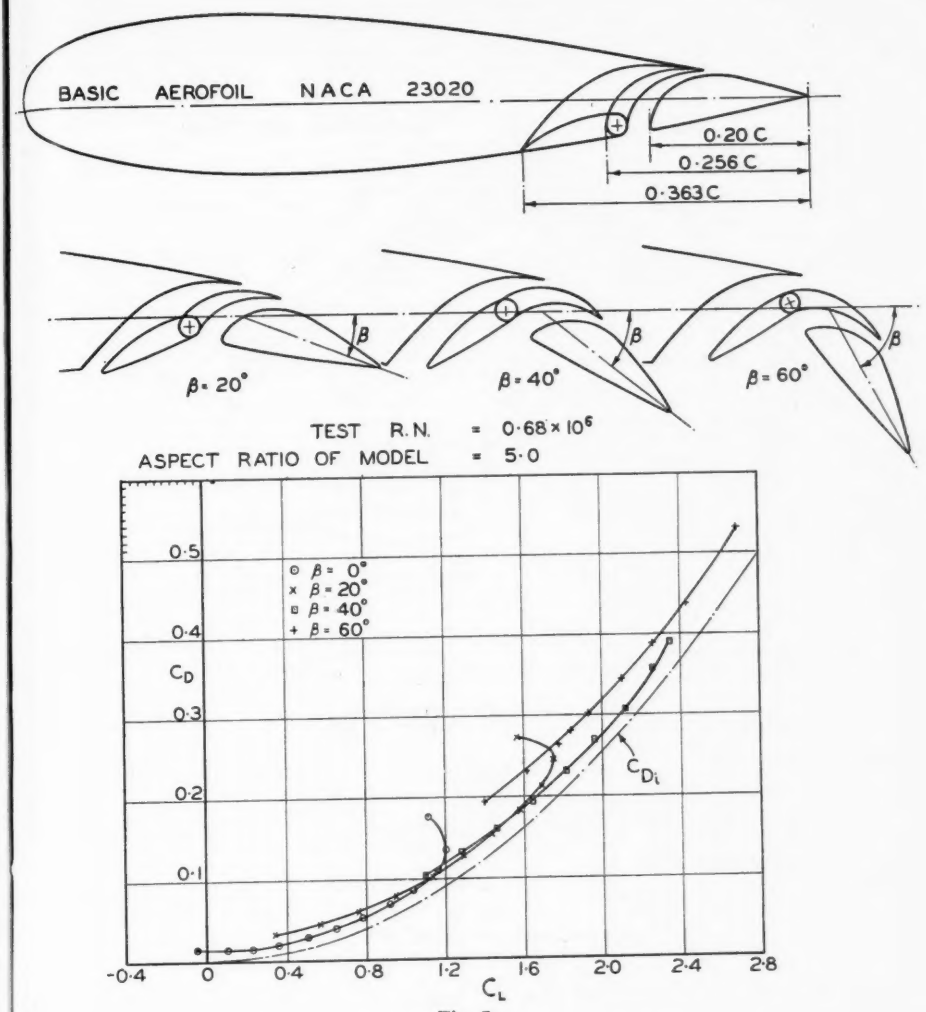

Fig. 7.
20 per cent. slotted flap with articulated eyebrow.

Flaps on swept-back wings used on high-speed aeroplanes present a special problem, particularly on sections with a sharp nose and a far-back maximum ordinate.

Some flaps tested on a swept-back wing are shown in Fig. 8 and the test results in Fig. 9. The following conclusions can be drawn from these results:—

(*i*) *Slotted flaps* will delay the angle of stall more than any of the other flaps tested, but are not able to give a big ΔC_L. The pitching moment curve is unstable and suggests that the slotted flaps delay the stall of the centre section—an undesirable feature.

(*ii*) *Junkers type of flap* shows up well in all respects. $C_{Lmax} = 1.66$ with a $0.3c$ flap set at 40°. Further tests were also made with Junkers type trailing edge flaps of $0.45c$. While C_{Lmax} was raised to 1.95, the test is of academic interest only, on account of the extreme size of such flaps.

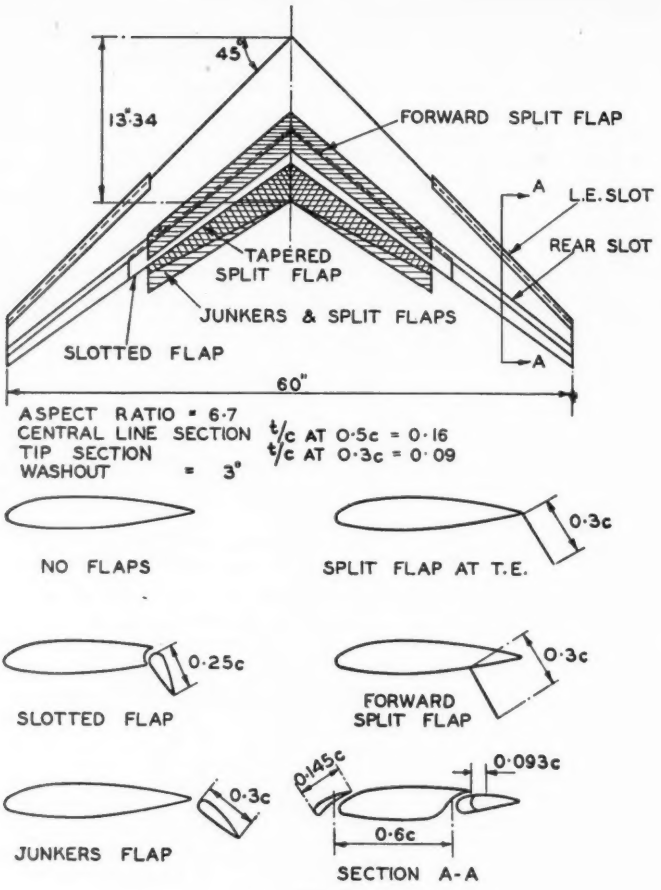

Fig. 8.
Swept wing model with different lift flaps.

Figure 10 shows that the Krüger type of nose flap has very similar characteristics (lift and pitching moment) to the H.P. leading-edge slot.

The action of a nose flap (Fig. 11) is to transfer the stagnation point from the critical sharp nose to the more stable rounded nose of the flap and, at the same time, to reduce the pressure gradient that would otherwise exist behind the sharp leading edge of the aerofoil. In this way early separation at the nose of the aerofoil is avoided and higher values of $C_{L\max}$ are developed.

As swept-back wings normally stall first at the tips, the addition of these nose flaps outboard, or the orthodox leading-edge slots, prove beneficial at the stall. Opinions are divided as to whether the leading-edge slots should be automatic or power-operated. Both methods have given satisfactory results.

The problems of change of trim resulting from the use of high-lift devices are but an extension of those associated with normal tailplane and elevator design. It is more economical to arrange first for a reasonable tail volume and then cover ground effects by detail design of the elevators. There should be a sufficiently large and unshielded portion of the elevators to give the necessary amount of tail-heavy pitching moment, *i.e.* the

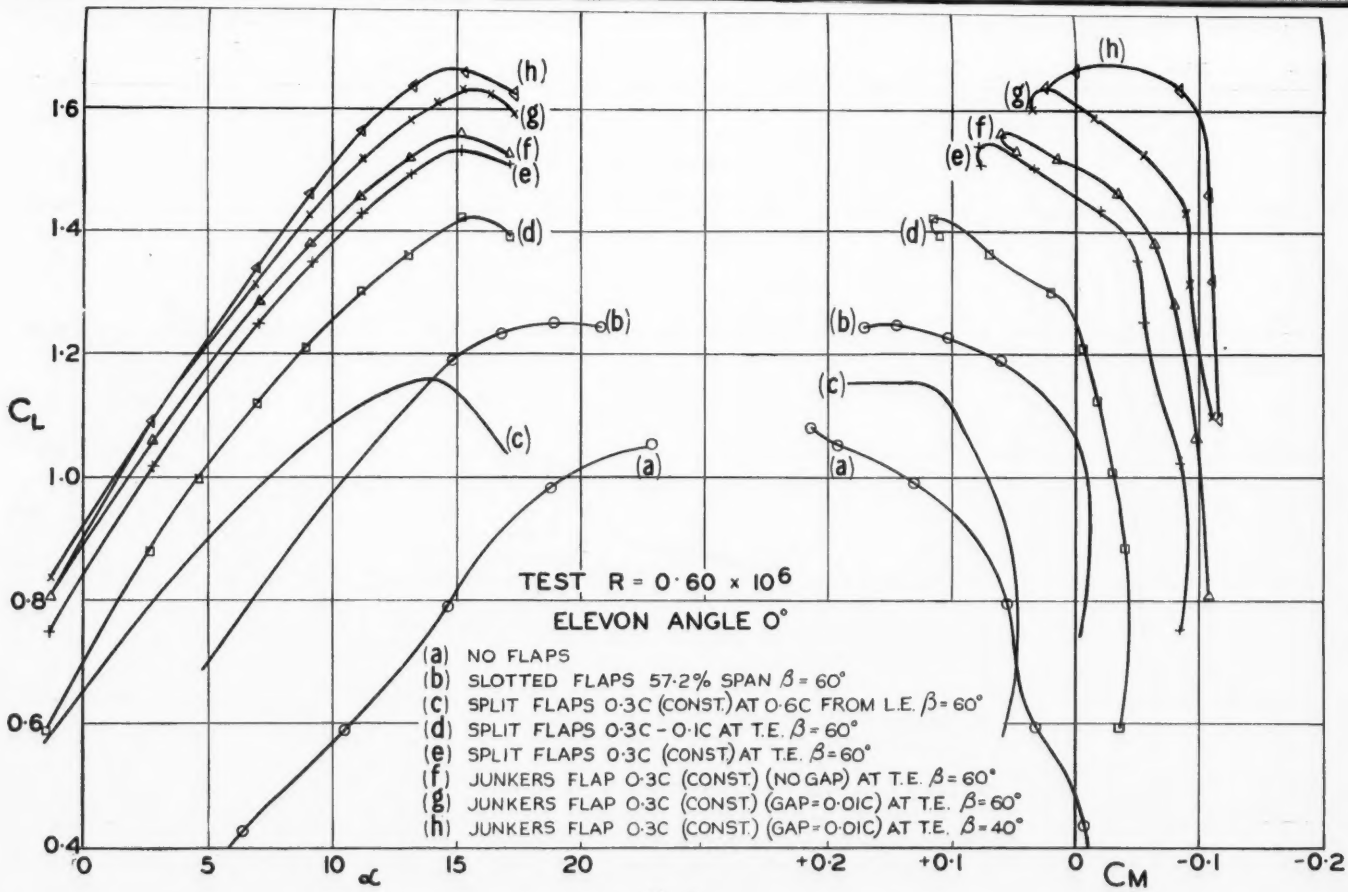

Fig. 9.
Effect of different types of flaps on C_L and C_M.

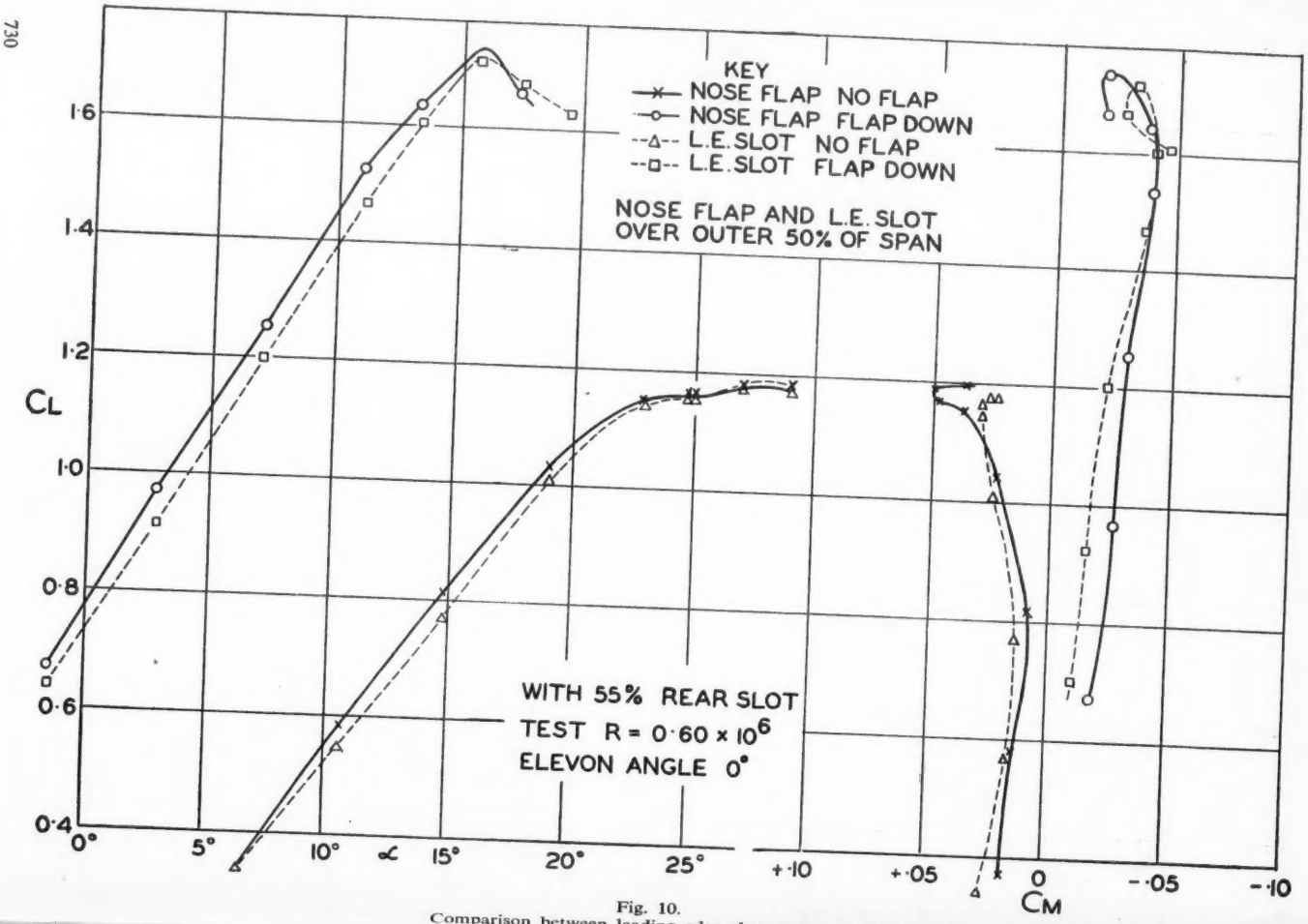

Fig. 10.
Comparison between leading edge slots and nose flaps (125°).

increase of zero-lift moment due to flap setting, plus the nose-heavy moment produced by the fixed tailplane.

4. *Boundary layer control.* Trailing-edge lift devices produce change in the camber of a basic wing and cause the entire pressure distribution to be stepped up. (If, in addition, the flap, by its rearward movement, increases the wing chord there is a further increment in the lift.) Table V shows that slotted flaps of all kinds give greater lift increments than split flaps. The additional lift is made possible because air which later has to flow over the upper surface of the flap is first speeded up by passing it through a venturi passage formed by the flap and the rear part of the wing, and then is used to energise the boundary layer. This permits the pressure distribution over the whole wing to be stepped up still higher. There is obviously a limit to what can be done by natural means. For greater lift increments artificial aids are needed to feed energy into the air flowing over the rear part of the wing. This becomes the basis of forced *boundary layer control for lift.*

Fig. 10. Comparison between leading edge slots and nose flaps (125°).

TABLE VI.

CHARACTERISTIC LIFT COEFFICIENTS FOR FULLY FLAPPED WINGS

	$C_{L\max}$	$\Delta C_{L\max}$ due to flap	Ref.
American Tests (Infinite aspect ratio)			
Plain wing (NACA 23012)	1.55	—	(1)
Plain wing, 0.2c plain flap	2.40	0.85	(1)
Plain wing, 0.2c split flap	2.55	1.00	(1)
Plain wing, 0.2c H.P. slotted flap	2.80	1.25	(1)
Plain wing, 0.2c slotted flap moved to rear (Fowler)	2.90	1.35	(1)
Plain wing, 0.3c slotted flap moved to rear (Fowler)	3.20	1.65	(2)
British Tests (Aspect ratio = 5.0)			
Plain wing (H.P.51) (t/c = 5.0)	1.13	—	(3)
Plain wing, 0.4c slotted flap moved to rear (Fowler)	2.95	1.82	(3)
Plain wing, 0.4c slotted flap with 0.1c split flap moved to rear (Fowler)	3.23	2.10	(3)
Plain wing, 0.4c double flap	3.57	2.44	(3)
Plain wing, 0.3c slat	2.27	—	(3)
Plain wing, 0.31c slat, 0.4c slotted flap moved to rear (Fowler)	3.89	1.82	(3)
Plain wing, 0.31c slat, 0.4c double flap	4.44	2.44	(3)

Refs. (1) NACA T.R. 664 Test R.N. 3.5×10^6
(2) NACA T.N. 808 Test R.N. 3.5×10^6
(3) British R. & M. 2180 Test R.N. 0.5×10^6

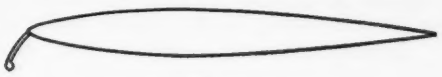

Fig. 11.
Krüger nose flap (lift device for swept wings).

A Royal Aircraft Establishment report, in 1941, gave the results of wind-tunnel tests on boundary layer control[7] to determine the quantity of air required and the power necessary. High lift coefficients up to 7 were obtained on two-dimensional models.

Wind-tunnel tests on boundary layer control showed that there was little difference in the power required, whether air was sucked into or ejected from a wing. (The two systems are shown diagrammatically in Fig. 12.) This, in turn, led to the proposal that the quantity of air required to give boundary layer control could be halved if air were sucked into the inboard half of the wing span and the same air afterwards ejected from the outboard half (Fig. 13). Even so, when the best sizes of slots for the combined scheme had been experimentally checked, it was found that the quantity of air to be moved per second was still extremely large and, consequently, the power required was excessively great.

In Appendix I the main principles of boundary layer control are described and have been applied to increase the values of $C_{L\max}$ to 5 on the Hermes IV. While the power required is dependent on the increase in lift desired, the losses in the duct system and so forth, increase considerably with increase in span and also with wing loading.

It is for reasons of excessive power required and weight involved that progress in the application of boundary layer control for increased lift has been disappointingly slow.

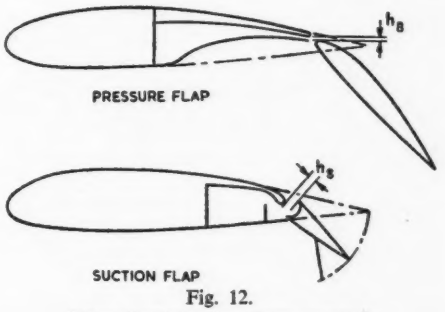

Fig. 12.
Flaps for boundary layer control.

Indeed, the Germans were the first to indicate a possible solution to the practical problems.

Among the first schemes that were examined and found too heavy in weight, was the use of a gas turbine to drive a blower. Then followed an interesting and important series of model and full-size ground tests[2-8] on the Arado 232, which used a rocket-operated feed-pump for the movement of the air to give boundary layer control (Fig. 13). Although rockets are not thermodynamically highly efficient, their simplicity and absence of moving parts make them inherently reliable and suitable units for the control of boundary layer and they are capable of being operated without undue risk.

If applied to an aeroplane similar to the Hermes IV the rocket would be used as a jet pump and directed as a multi-nozzle jet (*see* Fig. 14) into a convergent mixing chamber. The fuel included would enable two take-off and two landing operations to be made, with a total endurance of 45 seconds an operation, or three minutes in all. The fuel would be hydrogen peroxide with calcium or sodium permanganate as the reactor. Hydrogen peroxide is then changed into steam and oxygen. The resultant jet speed out of the reaction chamber would be of the order of 3,500 ft./sec. (1,160 m./sec.) and the temperature in the reaction chamber about 500°C. The jet would be mixed with air so that the resulting temperature of the jet discharged as steam over the wing would be reduced to about 100°C.

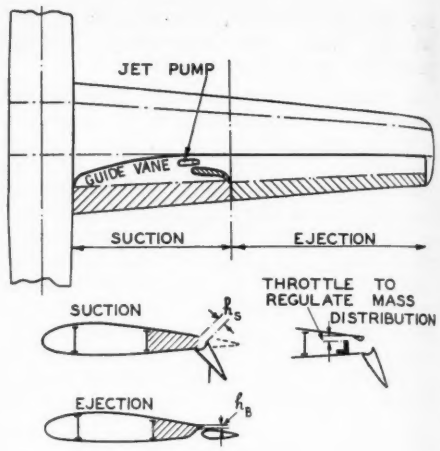

Fig. 13.
Arado 232 boundary layer control (combined arrangement).

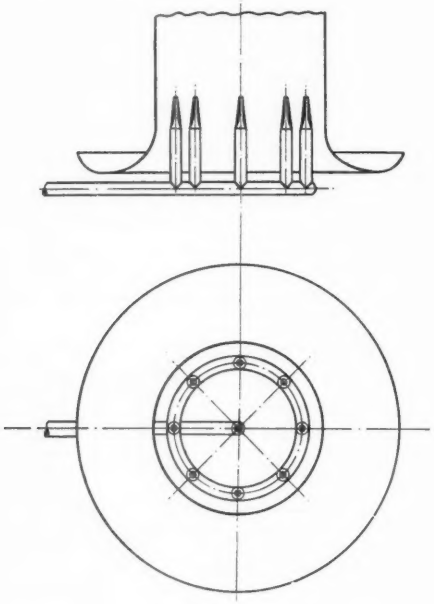

Fig. 14.
Circular group of nine power nozzles.

Data on wings having different types of flaps subjected to boundary layer control are not so full as for normal flaps, but it is possible to give some general conclusions.

1. British tests[1] show there is an economy (up to $C_{L\max}=6.0$) in the quantity of *pressure* air used as the flap chord is increased. The same holds good for the power required. This suggests that one should use as big a flap chord as possible and have a rearward translational, as well as a rotational, movement. These results are in good agreement with what one would have forecast from normal flap tests.
2. German tests[2] show that, where *suction* is used for boundary layer control of lift, the efficiency of the flap falls off when the chord is increased above about 25 per cent.
3. Experimental evidence indicates that the size of the slots in the wing should be different for the two systems. For pressure slots the ratio slot depth/chord should be 0.0075, whereas for suction slots the ratio should be 0.03.

The following are the main conclusions of the analysis given in Appendix I.

1. The power required to operate boundary layer control for lift is proportional to (wing loading)$^{\frac{3}{2}}$. This makes it costly in power for modern civil air transports with high wing loadings of 60-80 lb./ft.^{2} (300-400 kg./m.^{2}). In the German experiments a wing loading of 24 lb./ft.^{2} (117 kg./m.^{2}) was used.
2. Aspect ratio is an important factor affecting the power required for boundary layer control, because it determines duct length and, to a large extent, duct losses. Thus, while the power required can be reduced if the aspect ratio is kept small, high aspect ratios must be used if induced drag is to be kept low. Here there are two conflicting considerations to be resolved by compromise in the design.
3. For aeroplanes similar to the Hermes IV the horse-power required to ensure a developed $C_{L\max}=5.0$ is just ten times that required for $C_{L\max}=3.0$ (Fig. 17 and Table VII). However, as the gain in take-off is not greatly improved for $C_L=5.0$ over that for $C_L=3.5$, there appears to be every reason to limit $C_{L\max}$ to 3.5, when the horse-power required (840) becomes reasonable and, on the assumption that a jet-pump is installed, the weight of the equipment and fuel is manageable (3,550 lb.) (1,660 kg.) (Fig. 18).
4. In order to reduce to a minimum the power required for the operation of boundary layer control, the wing system should be as efficient as possible; this would lead to a preference for full-span flaps with possibly spoiler lateral controls.

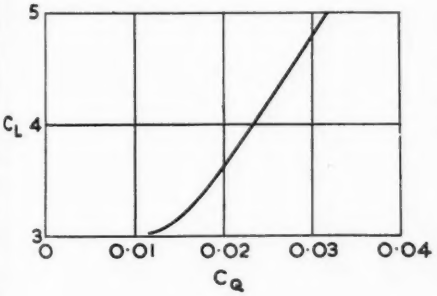

Fig. 16.
Relationship between C_L and C_Q (experimental) from R.A.E. Rep. B.A.1669.

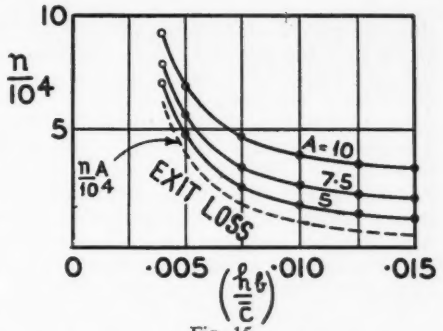

Fig. 15.
Pressure loss coefficient $n=\Delta P/(qC_{Q_s}{}^2$ as a function of A and $h_t/\bar{c}$. The curves are for a combined boundary layer control system where diameter of pump/mean chord $(D/\bar{c})=0.12$, diameter of hub of pump/$D=d/D=0.5$, $(h_s/\bar{c})=0.003$. $S_s/S_b=1.0$.

5. A most interesting conclusion comes from the comparison between the effects of boundary layer control during take-off and rockets used directly to augment thrust at take-off. Fig. 19 amplifies information already given on Fig. 4 as it indicates the ground run, the distance from take-off to climb 50 feet and the total distance on the ground from the air to reach 50 feet height. It is important to note that whereas boundary layer control enables a reduction to be made in the ground run—by far the greater part of the total run—rockets will not lower the stalling speed of the aeroplane at all but will only make possible a reduction in the distance from take-off to climb to 50 feet (through an increase in the available rate of climb).

   An actual example based on the Hermes IV will make this clear:—

   If boundary layer control equipment is used to increase $C_{L\max}$ to 4.0 (fuel required for *one* take-off 3,790/4 or 948 lb. (430 kg.) *see* Fig. 18 and Appendix) the ground run is reduced from 1,293 yards (1,180 m.) ($C_{L\max}=1.8$) to 540 yards (490 m.) (Fig. 19), and the distance covered from then on to climb to 50 ft., from 337 yards (307 m.) to 230 yards (210 m.). The total distance covered to reach a height of 50 ft. is 770 yards (700 m.).

   If rockets are used to increase the thrust for take-off, the ground run will be practically unchanged, because owing to the short duration of the rocket (9 seconds) it can only be operated towards the end of the ground run to reduce the distance to climb 50 feet. In

this example the added thrust will be 9,480 lb. (4,300 kg.) and this will reduce the distance before a height of 50 feet is reached on the climb from 337 yards (307 m.) to 76 yards (70 m.). The total distance covered to reach a height of 50 feet is 1,293 + 76 = 1,369 yards (1,180 + 70 = 1,250 m.).

Rockets will thus prove more beneficial during take-off if used to augment lift rather than thrust. They cannot, of course, have any effect on the landing run length, such as is obtained with boundary layer control.

Of the four methods of increasing lift which have been discussed, that of forced boundary layer control offers the greatest promise for further development. With high wing loading, such as 50-60 lb./ft.^{2} (250-300 kg./m.^{2}), it would probably not be profitable to use $C_{L\max}$ greater than 4. Although the equipment and fuel would involve an addition to the basic equipped weight at take-off of some 5,200 lb. (2,360 kg.), it should be possible to climb over the 50 ft. barrier without exceeding 900 yards (820 m.) for the total run, even with the operational take-off weight increased by 10,000 lb. (4,500 kg.). In consequence, not only would there be a saving in runway length, but also there would be an increase in operational load that could be carried.

These results are based on forced boundary layer control with flap schemes already tested. It is reasonable to expect that developments will make possible still further improvements in performance. While the boundary layer control system adds complications, the actual flap system would be simpler than for normal high-lift devices. This would make for certain weight-saving which has not been taken into account in the foregoing analysis.

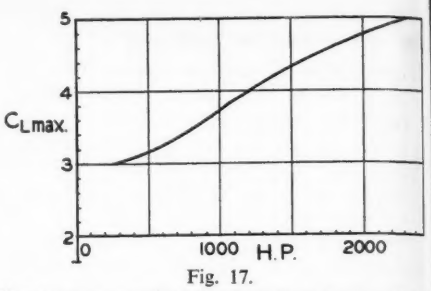

Fig. 17.
Horse-power required for boundary layer control.

THE TAKE-OFF AND LANDING PROBLEM

High-lift devices, by reducing minimum flying speeds, take-off and landing runs, lessen runway requirements.

A question now to be considered is how far improvements in equipment for take-off and landing can reduce the size or perhaps eventually eliminate the need for concrete runways, which make up the principal costs in aerodrome construction.

Undercarriages for current air transports weigh from 4 per cent. to 6½ per cent. of the all-up weight. It is not surprising therefore that this component has been scrutinised from time to time to see if its weight can be reduced or if the undercarriage cannot, in fact, be eliminated. If a weight break-down of the Hermes IV is examined it is found that the weight of the undercarriage units is some 3,500 lb. (1,590 kg.) (4.24 per cent. W) or almost 25 per cent. of the actual payload. Although the weight is reasonable by present standards, the potential payload lost is considerable. This is particularly the case for aeroplanes required to operate a non-stop

TABLE VII.

C_L =	3.0	3.5	4.0	5.0
$10^4 C_Q{}^3$ =	0.0152	0.0686	0.1216	0.328
$C_L{}^{\frac{3}{2}}$ =	5.2	6.55	8.0	11.18
$\frac{n C_Q{}^3}{C_L{}^{\frac{3}{2}}}$ =	0.0121	0.0432	0.0628	0.121
h.p. =	235	840	1,220	2,350
$V=\left(\frac{W}{S}\cdot\frac{2}{\rho}\cdot\frac{1}{C_L}\right)^{\frac{1}{2}}$ =	130	120.6	112.7	101
$Q=C_Q S' V$:				
ft.^{3}/sec. =	1,055	1,610	1,820	2,270
lb./sec. =	80.7	123.0	139.0	174.0

London-New York service, where the payload may be no greater a percentage of the all-up weight than that of the landing gear.

Before the possibilities of an undercarriage-less aeroplane are examined, consider first some of the fundamental problems. In order to land, the pilot will endeavour to lose all vertical velocity on the aeroplane and while it is normally not more than about two ft./sec. (0.6 m./sec.) it is usual to provide for contingencies by making the aeroplane capable of withstanding loads set up when the vertical velocity is as high as 11 ft./sec. (3.35 m./sec.).

On impact with the ground the kinetic energy of the aeroplane (in a vertical direction) must be dissipated by means of a resistance force provided either on the aeroplane or on the ground. Practice has generally put the shock-absorber on the aeroplane in the well-known pneumatic wheel and oleo-leg arrangement, and it is this established component which we are now critically reviewing and seeking to modify.

Examples of types already in operation in which normal undercarriages are not employed are:—

(*a*) A flying boat which uses water as the natural medium to take the shock of landing, and

(*b*) An aeroplane fitted with an arrester gear to pull it up and, at the same time, force it down to make a belly-landing on to a resilient mat providing the shock-absorbing device. This method has been developed in the United Kingdom to enable Naval aeroplanes to be landed on aircraft carriers.

It will be as well to state the requirements of any method of take-off and landing, as the extent to which these requirements are met will determine the success, or otherwise, of the method.

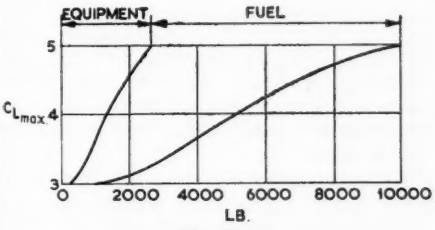

Fig. 18.
Weight of boundary layer control fuel and equipment.

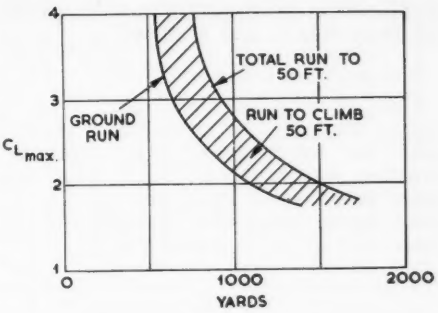

Fig. 19.
Hermes IV (85,000 lb.) ground run and total run to 50 feet.

Desirable requirements are:—

1. The take-off and landing of normal aeroplanes should not be interfered with.
2. The landing area should be cleared as quickly as possible, certainly without an increase on present-day times.
3. Taxi-ing of the modified aeroplane should be done as easily as at present.
4. Initial cost and subsequent upkeep should be considerably less than that of the runways normally provided.
5. Operation should be simple and reliable so that passengers' confidence is retained.

With these facts in mind some possible means other than the normal undercarriage can be examined.

Flying Boats

Strictly speaking a flying boat base is not an alternative to a land airport, but reference to it must be made before the problem of the airport is considered. In spite of its attractions, the flying-boat has had only moderate success and, at the present time, its future is uncertain. It is probably true to attribute the present preference for the aeroplane over the seaplane to the world-wide establishment of aerodromes and aerodrome facilities during World War II. It is against aeroplanes using these established facilities that flying boats have to compete. Apart from engineering or aerodynamic considerations, the flying boat is restricted to limited bases to a greater extent than land planes. It is not possible within the limits of this paper to develop a fully reasoned case for and against the flying boat and, in any case, it is unlikely that it can be safely

prophesied at the present time what will be its future role in civil aviation.

Catapult launching

Catapult launching, and landing on a special mat with the assistance of arrester gear, are more suited to the particular problems associated with carrier-borne aircraft than to civil transports operating at busy airports, where lack of mobility would make such a scheme unworkable.

Other methods

The undercarriage-less aeroplane

A return to the lower tyre pressures which were customary before concrete runways came into being would permit grass aerodromes to be used once more; but for modern aircraft the number of wheels necessary would be excessive and their stowage (when retracted) impossible. The substitution of track undercarriages for wheels would give an aeroplane that greater freedom of operation on grass which the caterpillar track vehicle has over a wheeled one; but the greater weight and heavier upkeep cost of the track undercarriage, compared with the normal-wheeled chassis, make its use unattractive.

A logical conclusion, so far as take-off is concerned, is to mount the track—or its multi-wheeled equivalent—on a bogie. The wheeled bogie would be provided with a sufficiently large number of wheels, so that with lower tyre pressures it could be operated from grass aerodromes. On this bogie the aeroplane is loaded and at the point of take-off the bogie is released from the aeroplane and left on the ground. An example of this method of take-off, on a small scale, is that of the provision of wheels underneath floats on float-type aeroplanes when the aeroplane is required to take off from a land base.

The take-off bogie, if required, can be power-driven to increase acceleration during take-off and reduce the take-off run.

If immediately the aeroplane is airborne, this ground bogie is left behind, the weight and drag of the extended undercarriage, which would otherwise be present, is eliminated. (The drag of the Hermes IV undercarriage, measured at 100 ft./sec. (30 m./sec.) amounts to 385 lb. (175 kg.) out of a total drag of 2,000 lb. (910 kg.) and its deletion would increase the rate of climb at take-off by 300 ft./min. (91 m./min.) or, would reduce the horizontal distance to climb to 50 ft. (15 m.) from about 300 yards (275 m.) to 220 yards (200 m.)—for 85,000 lb. (38,600 kg.) all-up weight.) In addition there would be a saving in undercarriage weight which would be available to increase the payload.

In place of the landing gear a skid undercarriage of sufficient height could be provided so that loading on to the take-off bogie could be carried out in much the same way as stillages are lifted on trucks for transport.

To land on skids would be but a development of the successful belly-landings which have been made with aircraft in emergency, generally with little damage to the fuselage, or to the airscrews on high-wing aircraft. On jet-propelled aeroplanes the question of propeller clearance does not arise and the problem is simplified.

The skid landing gear braking effect would be better than with present tyres and the troubles of locked wheels causing tyres to be scrubbed on concrete runways would be eliminated.

The attraction of skid landing becomes evident when advantage has been taken of high-lift devices to reduce the minimum flying speed. If the touchdown speed is reduced from 120 m.p.h. (191 km./hr.) to 70 m.p.h. (112 km./hr.) the amount of kinetic energy to be transformed into heat will be reduced in the ratio $(70/120)^2$ or, to one-third of what it would otherwise have been, and the temperature rise would be correspondingly reduced.

While the theoretical advantages in favour of bogie launching and skid landing are evident, equally so are the practical difficulties which have to be overcome before operation of this method is successful. So far, little development work has been done on this type of design.

Either an aircraft would have to be adapted to take some common type of bogie, which would impose limitations on the design of the aeroplane, or alternatively, each aeroplane would require its own type of bogie at each aerodrome at which landings were to be made. Thus, while some of the desirable requirements listed would be met, others, such as those relative to cost, need further consideration after there has been more development.

On trans-Atlantic services where the payload forms only a small percentage of the all-up weight, the gain in payload (if the whole or the majority of the undercarriage weight is saved) is so substantial that there is

a promising case for the immediate development of the undercarriage-less aeroplane.

It would perhaps be strange if there were a return to this method of launching and landing, for it is the method by which the Wrights originally made their classic flights—with a pylon and rail to launch their aircraft and skids upon which to land it.

Tricycle and castoring undercarriages

It is clear from the earlier analysis that runway lengths and, therefore, aerodrome costs, can be greatly reduced if there is a reduction in minimum flying speed. If the use of concrete runways is retained, a further saving in aerodrome costs can be effected if airports can be operated with a single uni-directional runway. For this to be possible, aeroplanes must be able to land with drift in a cross-wind.

The use of the tricycle undercarriage has made possible landing in cross-winds, but such operations impose on the undercarriage higher loads which may be reduced by the use of the castoring undercarriage. With this device the aeroplane may approach and fly on to the runway in a somewhat crab-like fashion but, with the wheels set round in the direction of the runway length, much less stress is imposed on the undercarriage. With such a device an aeroplane can make use of runways with high cross-winds, but at the expense of some added weight to the undercarriage. Here again there would be a reversion to a pioneer type of undercarriage, for the castoring type of landing gear was a feature of the original Bleriot monoplane.

If the tricycle undercarriage be increased in strength to withstand landing in high cross-winds, or if a castoring undercarriage be used, uni-directional runways can be used to a greater extent than at present. Such runways would greatly simplify navigational aid systems for use in bad weather, as well as the positioning of airport buildings and taxi strips.

GENERAL CONCLUSIONS

It has been seen that to achieve faster speeds the designer has cut down parasitic drag and reduced the wetted area of an aeroplane to a minimum. These have been done at the expense of minimum flying speeds which are now greatly in excess of those of 20 years ago. As a result, runs for both take-off and landing have increased enormously, and landing strips have been extended from about 3,000 ft. (900 m.) to as much as 10,000 ft. (3,000 m.) in order to ensure a maximum of safety during take-off and landing operations. This policy has led to an astronomical rise in the costs of modern civil airports and their annual upkeep charges are of national concern.

In order to counter this undesirable state of affairs the paper has examined what contributions the aeroplane designer can make to ease the present position. It has been pointed out that high-lift devices, which control the boundary layer naturally or artificially, provide the most effective method of removing some of the present handicaps to operator and airport authority alike.

The employment of rocket devices to provide forced boundary layer control to give added lift appears to be one of the most promising means the designer has for the material reduction of minimum flying speeds. If minimum flying speeds are reduced, the great advantages that derive from high-lift devices are that the aeroplane is not increased in size nor is the cruising speed or payload adversely affected. But, besides the operational gains just mentioned, reduced minimum flying speeds give secondary advantages which are no less important, namely, greater safety in take-off and landing and the possibility of an extension of air transport to the undeveloped and under-populated regions. For feeder work, such as this implies, grass aerodromes are feasible; whether or not they can be used instead of prepared concrete runways is dependent upon whether or not undercarriage developments will make it possible. With the modern trend towards uni-directional runways in place of the present triangulated runway schemes, the added value of lower minimum flying speeds is at once evident. With distances for take-off and landing reduced to 900 yards, it becomes possible to use one landing strip, with airport buildings situated centrally. Thereby, and despite concrete runways, a most valuable reduction in airport costs and upkeep is possible. For the interim period, existing aircraft which require long runs for take-off and landing would still be able to utilise the entire uni-directional runway if, for these special cases, permission were granted. The uni-directional runway appears to be a logical conclusion for standardisation in the immediate future. It is particularly attractive because navigational facilities are

considerably eased and the air pattern of airport control greatly simplified.

A final but no less important development, which is recommended for serious study, is the adoption of simpler arrangements of undercarriages, which become rational when minimum speeds have been reduced to about 70 miles an hour.

APPENDIX I

Boundary Layer Control

Commonly used expressions and formulae

S = gross wing area (ft.²)

S' = wing area associated with boundary layer control flow coefficient C_Q (ft.²)

$\bar{c}$ = mean wing chord

Q = total quantity sucked into or ejected from the wing (ft.³/sec.)

C_Q = flow coefficient from $Q = C_Q S' V$; hence $V = (Q/S')(1/C_Q)$

V = free-stream velocity (ft./sec.)

q = free-stream stagnation pressure = full ram pressure of $\frac{1}{2}\rho V^2$ (lb./ft.²)

b = span of wing (ft.)

h_s, h_b = slot width on wing for suction or blowing, respectively (Fig. 12) (ft.)

ΔP = pressure head at any point, + for pressure, − for suction (lb./ft.²)

C_p = static pressure coefficient, from $P = C_p q$

W = weight of the aeroplane (lb.)

C_L = lift coefficient, from $W/(qS)$

In the ideal case, air enters the wing by suction and leaves by ejection with no energy loss within the wing. Under these conditions, the pressure head required will be made up of two parts.

ΔP_1 which measures the difference in pressure at the entry and the exit from the wing,

and ΔP_2 which measures the kinetic energy lost at exit.

Hence, ideal power required $= Q(\Delta P_1 + \Delta P_2)$
and h.p. required $= Q(\Delta P_1 + \Delta P_2)/(550\,\eta)$

where η = efficiency of the feed pump.

In practice, however, there are considerable losses within the wing caused by duct friction, expanding passages, bends and throttle plates. To a good approximation[5] the main losses can be assumed to be proportional to the square of the internal velocity, *i.e.* power required $= Q(\Delta P_1 + \Delta P_2 + \Delta P_3)$ where ΔP_3 represents the internal losses and where the internal velocity is converted from Q/a to Q/S', where a is the cross-sectional area of the wing duct at the point considered.

Then Power $= Q \Sigma \Delta P = Q n (\rho/2)(Q/S')^2$ and h.p. required, taking efficiency of the feed pump as η is

$$\frac{Q \Sigma \Delta P}{550\,\eta} = \frac{C_Q S' V}{550\,\eta} n \left(\frac{\rho}{2}\right)\left(\frac{Q}{S'}\right)^2$$

$$\text{But } \frac{Q}{S'} = C_Q V = \frac{C_Q S'}{550\,\eta}\left(\frac{\rho}{2}\right) n C_Q^2 \left(\frac{W}{S}\frac{2}{\rho}\frac{1}{C_L}\right)^{\frac{3}{2}}$$

$$\text{since } V = \left(\frac{W}{S}\frac{2}{\rho}\frac{1}{C_L}\right)^{\frac{1}{2}}$$

$$\text{or h.p.} = \frac{1}{550\,\eta}\frac{\rho}{2} S' \left(\frac{W}{S}\frac{2}{\rho}\frac{1}{C_L}\right)^{\frac{3}{2}} n C_Q^3 \qquad (1)$$

Estimates for n may be obtained from the following approximate expression, which applies to a trapezoidal wing of 1:2 taper.

$$n = n_1 + n_2 + n_3 + n_4.$$

where n_1 = *exit loss factor* $= (\bar{c}/h_b)^2$

n_2 = *diffuser loss factor*, which depends primarily on the blower or *jet pump diameter* (D) and the aspect ratio of the wing (A)
$= 4.9\,(A - 0.9)^2\,(\bar{c}/D - 4.8)^3$

n_3 = *entry loss factor* $= 1.2\,(\bar{c}/h_s)^2$

n_4 = *aspect ratio loss factor* $= 10^2\,(A - 0.3)^2$.

Typical values for n are plotted in Fig. 15 from which it will be apparent that n, and hence the power required for boundary layer control, is largely dependent on the slot-width ratio ($h_b/\bar{c}$) and on the aspect ratio (A) of the wing. On the same diagram a curve has been drawn showing the exit loss separately (dotted line) which shows that this loss increases as ($h_b/\bar{c}$) decreases. It is also seen how aspect ratio affects n since n for $A = 10.0$ is approximately twice that for $A = 5.0$.

Usual slot widths have been found from tests to be:—

Suction $(h_s/\bar{c}) = 0.03$.

Ejection $(h_b/\bar{c}) = 0.0075$.

Example:—For Hermes IV where $(h_s/\bar{c}) = 0.03$; $(h_b/\bar{c}) = 0.0075$; $A = 9.06$; $\bar{c}/D = 1/0.12$.

$$n = n_1 + n_2 + n_3 + n_4$$

$$n_1 = \left(\frac{1}{0.0075}\right)^2 = 1.78 \times 10^4$$

$n_2 = 4.9(9.06-0.9)^2\left(\frac{1}{0.12}-4.8\right)^3 = 1.445\times10^4$

$n_3 = 1.2\left(\frac{1}{0.0075}\right)^2 = 0.133\times10^4$

$n_4 = 10^2\ (9.06-0.3)^2 = 0.768\times10^4$

Hence $n = (1.78+1.445+0.133+0.768)10^4$

$n = 4.126\times10^4$.

We can now find for the Hermes IV the feed power required to obtain a series of values of $C_{L\max}$ using the above value for n (which will be constant for the aircraft).

From Fig. 16 are obtained values of C_Q necessary to get the required $C_{L\max}$. They are:—

$C_{L\max}$	3.0	3.5	4.0	5.0
C_Q	0.0115	0.019	0.023	0.032

Using equation (1) we have, rearranging,

$$\text{h.p. required} = \left[\frac{1}{550\,\eta}\sqrt{\left\{\frac{W}{S}W^2\frac{2}{\rho}\right\}\frac{S'}{S}}\right] n\,\frac{C_Q{}^3}{C_{L^{\frac{3}{2}}}}$$

where the constants are:—

$W/S = 60.4$ lb./ft.^{2}; $W = 85{,}000$ lb.;

$\rho = 0.002378g$ lb./ft.^{3}.

$n = 4.126\times10^4$ and $S'/S = 0.5$. $\eta = 0.9$.

Hence, $\left[\frac{1}{550\,\eta}\sqrt{\left\{\frac{W}{S}W^2\frac{2}{\rho}\right\}\frac{S'}{S}}\right] = 19{,}450.$

and therefore h.p. required

$$= 19{,}450\times4.126\times10^4\ C_Q{}^3/C_{L^{\frac{3}{2}}}.$$

The values of horse-power required are plotted on Fig. 17.

From the tests carried out for the Arado 232 wing[6] it was found that for $C_L = 4.0$, the amount of propellant (hydrogen peroxide) consumed was 27.8 kg./(C.V. hour) and the dry weight of the jet pump units was 0.5 kg./C.V.

Hence, for the Hermes, the weight of propellant required for 3 minutes endurance (two take-offs and landings) will be $27.8\times2.235\times1{,}220/20 = 3{,}790$ lb. where 2.235 is the conversion factor to change kg./C.V. into lb./h.p.; the jet pumps would weigh $0.5\times2.235\times1{,}220 = 1{,}365$ lb. Hence, total weight of boundary layer control equipment (fuel and units) for $C_{L\max} = 4.0 = 5{,}115$ lb.

Calculations were made for the other values of C_L and the results (plotted on Fig. 18) can be summarised as:

$C_{L\max}$	3.0	3.5	4.0	5.0
Weight lb.	993	3,550	5,155	9,930

It is interesting to see how modern high wing loadings and big aspect ratios influence the power required, and to demonstrate these points the German data[3] obtained for the Arado full-scale mock-up tests is used to arrive at the horse-power required for the Hermes. It will also serve as a check on the foregoing calculations.

Arado 232 data	*Hermes data*
$W = 35{,}200$ lb.	85,000 lb.
$S = 1{,}452$ ft.^{2}	1,408 ft.^{2}
$W/S = 24.2$ lb./ft.^{2}	60.4 lb./ft.^{2}
$A = 7.5$	9.06
$n = 3.39\times10^4$	4.126×10^6

Horse-power (C.V.) = 260 for $C_L = 4.0$.

Now from (1) we see that h.p. varies as $S\ (W/S)^{\frac{3}{2}}\ n$. Therefore using the Arado data to estimate the Hermes horse-power required, we have

$$\text{h.p. required} = \frac{260}{0.986}\times\frac{1{,}408}{1{,}452}\left(\frac{60.4}{24.2}\right)^{\frac{3}{2}}\times\frac{4.126}{3.39}$$

$= 1{,}226$ h.p., which agrees very well with the calculations in Table VII (1,220 h.p.).

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Following the Third Louis Bleriot Lecture a dinner was given by the Council of Association Française des Ingenieurs et Téchniciens de l'Aéronautique at the Aero Club de France, at which speeches were made by Monsieur Jarry, Sir John Buchanan, Sir Frederick Handley Page and, in the absence of Monsieur Marsselli, the French Air Minister, by his Chef du Cabinet, Monsieur Barton.

The following were among the many guests invited to the dinner:—

M. Armandias, Directeur Sté Messier and A.F.I.T.A. representative in London.

Air Commodore F. R. Banks, C.B., F.R.Ae.S., Associated Ethyl Co. Ltd.; M. Barton, Directeur du Cabinet de M. le Secrétaire d'E'tat à l'Air; K. J. G. Bartlett, Esq., A.F.R.Ae.S., Director, The Bristol Aeroplane Co. Ltd.; E. L. Bass, Esq., F.R.Ae.S., The Shell Petroleum Co. Ltd.; H. G. Bloss, Esq., A.F.R.Ae.S., Ministry of Supply; E. C. Bowyer, Esq., Director, The Society of British Aircraft Constructors; M. Louis Bréguet, Hon.F.R.Ae.S.; Leonard Bridgman, Esq., A.R.Ae.S., Editor, *Jane's All The World's Aircraft*; Sir John Buchanan, C.B.E., F.R.Ae.S., President, The Royal Aeronautical Society.

R. H. Chaplin, Esq., F.R.Ae.S., Hawker Aircraft Ltd.; A. C. Campbell-Orde, Esq., C.B.E., Technical Development Director, B.O.A.C.; E. G. Campbell-Voullaire, Attaché, British Embassy; M. Rolf Cape, Lieutenant Colonel, Officier Supérieur de Liaison Technique Aéronautique (U.S.A.); Colonel Carr, British European Airways; Air Marshal Colyer, Civil Air Attaché, representing the British Ambassador; H. G. Conway, Esq., F.R.Ae.S., Director, British Messier Ltd.

Ingénieur en Chef Daum, Western Union Military Supply Board, London.

L. G. Frise, Esq., F.R.Ae.S., Chief Designer, Percival Aircraft Ltd.

M. G. Gilles, Président Fondateur de l'A.F.I.T.A.; R. B. Godfree, Esq., A.F.R.Ae.S., Esso Export; Air Vice Marshal R. A. George, C.B., C.B.E., M.C.

Sir Frederick Handley Page, C.B.E., Hon.F.R.Ae.S., Chairman and Managing Director, Handley Page Ltd. (Past President of the Society); Ingénieur Général Harlaut, Directeur de l'Ecole Nationale Supérieure de l'Aéronautique; A. S. Hartshorn, Esq., F.R.Ae.S., Scientific Liaison Officer, British Embassy; M. Hedde, Esq., Ethyl S.A.; J. P. Herriot, Esq., A.F.R.Ae.S., representing Rolls-Royce, Ltd.

Captain J. J. Ide, National Advisory Committee for Aeronautics.

Thurston James, Esq., Editor *The Aeroplane*; Howard Johnston, Esq., Naval Attaché British Embassy.

Dr. T. von Kármán, Hon.F.R.Ae.S.

D. Lambert, Esq., A.R.Ae.S., Technical Representative, Armstrong Siddeley Motors; M. Le Royer, de Havilland Aircraft Co. Ltd.; W. H. Lindsey, Esq., F.R.Ae.S., Chief Engineer, Armstrong Siddeley Motors; M. Réne Lucien, F.R.Ae.S., Président Sté Messier.

Colonel MacClosky, U.S. Air Forces, representing the American Ambassador; G. H. Morel, Esq., Sté Commerciale et Industrielle Franco-Britannique.

M. Nestler; M. Nicholson; R. Ninnes, Esq., F.R.Ae.S., Engine Division, The Bristol Aeroplane Co. Ltd.; J. D. North, Esq., F.R.Ae.S., Managing Director, Boulton Paul Aircraft Ltd.

W. G. A. Perring, Esq., C.B., F.R.Ae.S., Director, The Royal Aircraft Establishment, Farnborough (Vice-President, Royal Aeronautical Society); Captain J. L. Pritchard, Hon.F.R.Ae.S., Secretary, The Royal Aeronautical Society.

N. Rowbotham, Esq., C.B.E., F.R.Ae.S., Director, The Bristol Aeroplane Co. Ltd.; N. E. Rowe, Esq., C.B.E., F.R.Ae.S., Controller of Research and Long Term Development, British European Airways (Vice-President, Royal Aeronautical Society); E. A. G. Rumbelow, Esq., representing *Flight*.

Ingénieur Général du Génie Maritime Sabine; J. E. Serby, Esq., D.D., F.R.Ae.S., Royal Aircraft Establishment, Farnborough; B. Shenstone, Esq., F.R.Ae.S., Chief Engineer, British European Airways; Air Commodore G. Silyn Roberts, C.B.E., Ministry of Supply.

A. E. Woodward-Nutt, Esq., F.R.Ae.S., Director of Military Aircraft Research and Development, Ministry of Supply.

The following day the British visitors were invited to Bretigny, the French equivalent of Boscombe Down.

THE DESIGN APPROXIMATION OF SKIN THICKNESS FROM STIFFNESS CRITERIA

by

A. H. HALL, A.R.Ae.S.

1. SUMMARY

A general approach and tentative solution has been indicated to the problem of estimating wing skin thickness from preliminary design data. The solution is presented in a form that permits calculations to be made quickly and with a minimum of effort.

In deriving the empirical formula relating perimeter and area of the aerofoil section, only symmetrical sections were considered. The amount of camber normally employed, however, should not alter the results appreciably.

While the problem has been dealt with only partially and as yet only tentative empirical coefficients have been suggested, it is hoped that the author's considerations of the problem will be of some interest and use at this stage.

2. INTRODUCTION

In designing to meet strength and aeroelastic requirements, the structural designer is faced with a simultaneous consideration of both the detailed structure and its overall behaviour. As these considerations have become more and more complicated, the designer has become more and more in need of simple formulæ which permit him, without extensive calculations, to keep the end point in view. In the formative stage of preliminary design, he further requires means by which he can readily predict the effects, on overall behaviour, of changing or varying local structural parameters. In these directions, he has already acquired many aids such as stiffness criteria, weight data and similar statistical data, which connect major parameters without becoming involved in the maze of finer detail. This paper falls roughly into that category, and is an attempt to provide a direct relation between wing stiffness and skin thickness, with the simplicity and accuracy required in preliminary design.

In stressed skin design, wing torsional stiffness is determined by primary torsional structure and inter-action of the primary bending structure, and is influenced additionally by such factors as taper, root restraint, cut-outs, diaphragms and method of jointing. In all, some twenty parameters, including physical dimensions and structural forms, may be listed as influencing the final wing stiffness. The problem is to cover all these in a simple relation which will be short and direct, yet sufficiently general for design use.

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Mr. Hall is a member of the Structures Laboratory, National Research Council, Canada.

A method by which this can be done is proposed here. It consists briefly, of obtaining a relation explicit in wing stiffness, skin thickness and skin taper, wing chord and chord taper, span, position of the aft shear web, aerofoil thickness ratio and spanwise variation of aerofoil thickness ratio. All other parameters, including deficiencies of the analytical approach, are covered in a composite coefficient which can be studied statistically by reference to existing wings. In this way, the coefficient can be broken down so far as is necessary to achieve satisfactory design accuracy.

NOTATION

A area of profile section included in torsion cell.

a empirical constant.

c wing chord.

d distance from leading edge to position of maximum aerofoil thickness.

G elastic modulus in shear.

h maximum thickness of aerofoil section.

k_{1i}, k_{2j}, k_3 stiffness ratios defined in text.

m_θ stiffness measured at wing reference station ($m_{\theta T}$ refers to torsion cell).

n empirical constant.

p perimeter of torsion cell.

s wing span outboard of root.

t skin thickness.

T concentrated torque applied at wing tip.

x distance from leading edge to most aft shear web.

y spanwise co-ordinate.

u y/s (u_r refers to reference station).

α A/c^2.

β wing plan taper parameter.

γ p/c.

ε aerofoil thickness-ratio taper parameter.

θ angle of twist.

κ $(1 + k_3 - \Sigma k_{2j})/\Pi k_{1i}$. (*See* equations (5*b*) and (5*c*).).

τ skin thickness taper parameter.

I_1 $\displaystyle\int_0^{u_r} \frac{du}{(1-\tau u)(1-\beta u)^3(1-\varepsilon u)^2}$

K $1/\prod_{i=1}^{i=p} k_{1i}$.

λ $1 - \sum_{j=1}^{j=q} k_{2j}$.

i, j, p, q, r integers.

Suffixes

i refers to structure inboard of wing root.

o refers to structure outboard of wing root.

r reference station.

R root.

T tip.

3. ANALYSIS

3.1. A GENERAL EQUATION FOR WING STIFFNESS

A completely general relation for stiffness measured at the wing reference section must be so constructed as to provide a continuous transition from stressed skin to differential span bending, and must provide distinction between symmetric and asymmetric twist. If the structure is considered in two sections, one lying between the aircraft centre-line and wing root, the other extending outboard of the wing root, then a concentrated torque at the tip will produce a rotation θ at the reference section such that

$$\theta=\theta_i+\theta_o$$

where θ_i is rotation of the wing root relative to the aircraft centre-line, and θ_o is rotation of the reference section relative to the wing root. It follows then that the stiffness measured at the wing reference station is given by

$$m_\theta=1/(1/m_{\theta_i}+1/m_{\theta_o})=m_{\theta_o}/(1+k_3) \quad . \quad . \quad . \quad (1)$$

For a given wing, k_3 will have two values, corresponding to symmetric and asymmetric twist. The stiffness m_{θ_o} may be derived primarily from either, or a combination of, a torsion cell, spars and stiffeners. It will be influenced by such secondary factors as cut-outs, root constraint, skin effectiveness, ribs, and so on. The resulting stiffness can be expressed in the approximate form

$$m_{\theta_o}=\left(\prod_{i=1}^{i=p} k_{1i}\right)m_{\theta_T}+\sum_{j=1}^{j=q}B_{2j} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where m_{θ_T} is the torsion cell stiffness and each of the coefficients k_{1i} represents the ratio of stiffness with, to stiffness without, the particular structural feature to which it refers. It is assumed that there is no inter-action between these coefficients, so that, for example, a cut-out for which $k=0.95$ and ribs for which $k=1.05$ will give a resultant $k=0.95\times1.05$. A similar additive relation will be presumed for the spars and stiffeners which are represented in the terms B_{2j}.

It will be convenient to make the B's non-dimensional by writing

$$B_{2j}=m_{\theta_o}k_{2j} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Hence

$$m_\theta=\frac{\prod_{i=1}^{i=p} k_{1i}m_{\theta_T}+m_{\theta_o}\sum_{j=1}^{j=q}k_{2j}}{1+k_3} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The form of equation (4) is sufficiently general for immediate purposes. Since m_{θ_T} will be proportional to G (the shear modulus), the coefficient Gk_{1T} will operate to carry the expression from a fully effective torsion cell, through sheet buckling, to fabric covering. The term $m_{\theta_o}\Sigma k_{2j}$ will vary from zero (pure torsion cell) to m_{θ_o} (differential spar bending). The denominator will account for the difference, if any, between symmetric and asymmetric twist.

It will be seen by referring back to equation (1), which is plotted in Fig. 2, that the limit of m_θ is m_{θ_i}, the inboard stiffness. The interesting feature of Fig. 2 is the rapid decrease in the rate at which m_θ increases when the outer wing alone is stiffened. The obvious fact is also apparent, that the optimum return for increasing the outboard stiffness is obtained when the inboard structure is infinitely stiff.

It will be convenient to write (4) in the form

$$\frac{m_\theta(1+k_3)-m_{\theta_o}\Sigma k_{2j}}{\Pi k_{1i}}=m_{\theta_T}, \quad . \quad . \quad . \quad . \quad . \quad (5a)$$

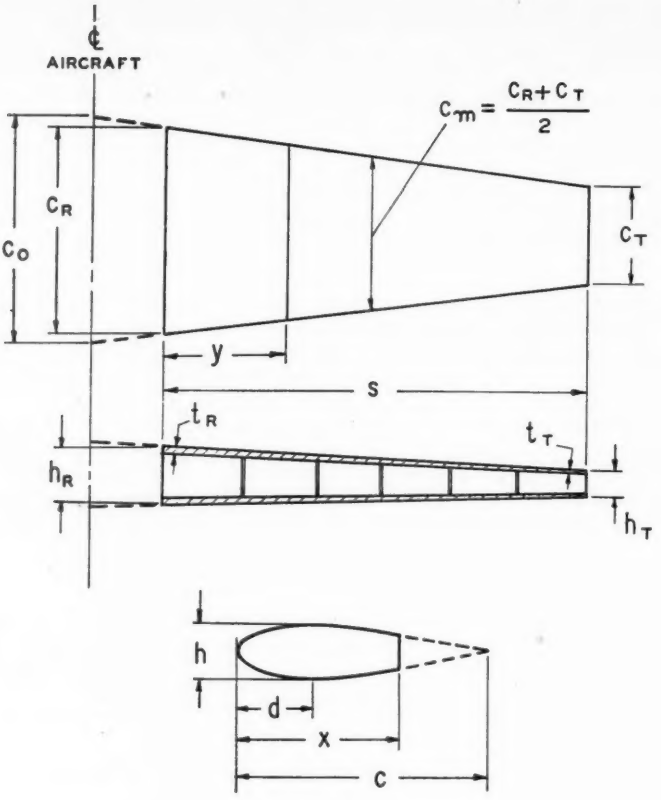

Fig. 1.
Diagram of wing plan and profile dimensions.

and since

$$m_{\theta_0}/m_\theta \simeq 1$$

$$m_\theta \frac{1+k_3-\Sigma k_{2j}}{\Pi k_{1i}} = m_{\theta T} \quad . \quad . \quad . \quad . \quad . \quad (5b)$$

or,

$$\kappa m_\theta = m_{\theta T}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (5c)$$

In this form, if a simple analytic solution is substituted for $m_{\theta T}$, the value of the coefficient of m_θ can be obtained, by reference to existing wings, in such detail as is necessary to make the equation sufficiently accurate for engineering purposes.

3.2 Analysis of $m_{\theta T}$

Considering the rate of twist

$$d\theta/dy = Tp/(4A^2Gt) \quad . \quad . \quad . \quad . \quad . \quad (6)$$

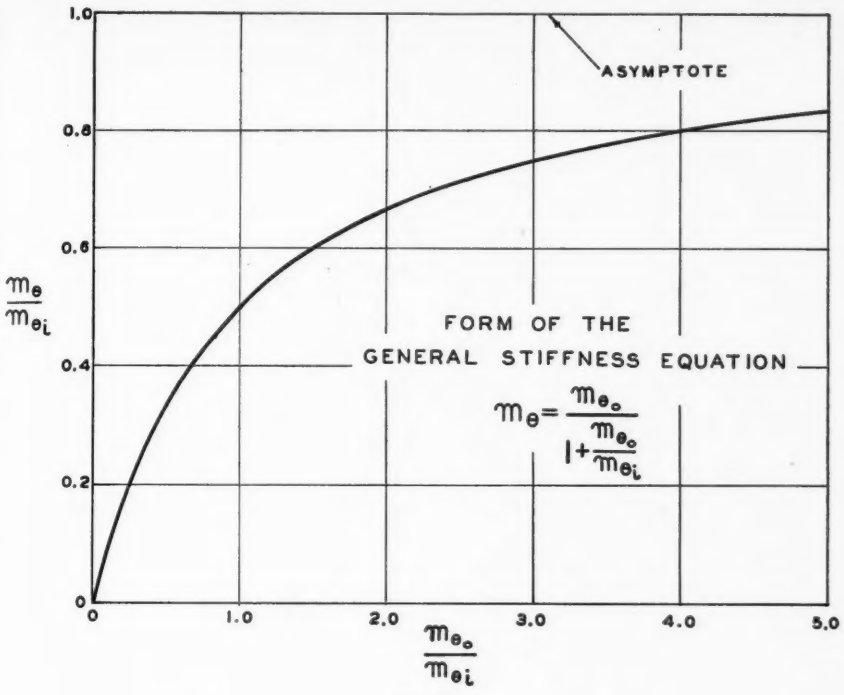

Fig. 2.

the perimeter and profile area can be written

$$\left.\begin{aligned} p &= \gamma c \\ A &= \alpha c^2 \end{aligned}\right\}, \qquad (7)$$

so that, if $y = us$

$$\frac{d\theta}{du} = \frac{Ts}{4Gtc^3} \cdot \frac{\gamma}{\alpha^2}. \qquad (8)$$

An empirical study of the parameter γ/α^2 has been made for a number of symmetrical aerofoil sections of different thickness ratios and positions of maximum thickness. The results, shown in Fig. 3, indicate a relation of the form

$$\gamma/\alpha^2 = a/(h/c)^n. \qquad (9)$$

Normally, the aft shear web of the torsion cell is determined by the requirements of ailerons and flaps, and this must be taken into account. The effect of terminating the torsion cell at various chordwise stations is shown in Fig. 3. It will be seen that there is little change in γ/α^2 for the loss of 25 to 30 per cent. of the trailing edge. When more is removed, the effect on a and n is shown in Fig. 4. For most practical cases, where the aft shear web is at 70 per cent. of the chord or more,

$$\frac{\gamma}{\alpha^2} = \frac{5.44}{(h/c)^{1.89}}. \qquad (10)$$

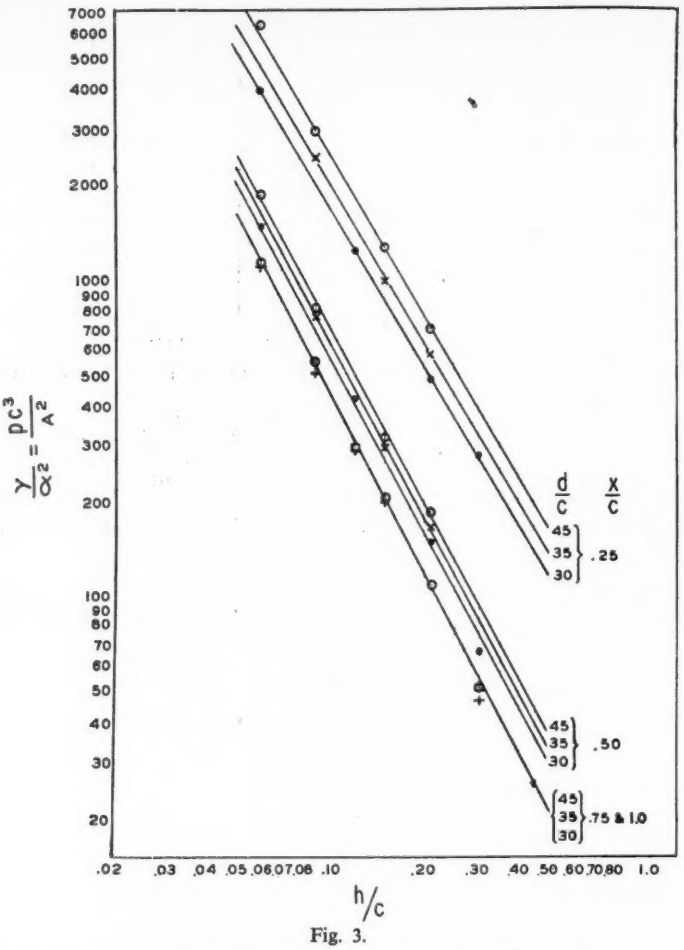

Fig. 3.

Aerofoil data supporting the empirical relation $\frac{\gamma}{\alpha^2} = \frac{Pc^3}{A^2} = \frac{a}{(h/c)^n}$.

Considering equation (8) with

$$\left.\begin{aligned} t &= t_R(1-\tau u) \\ c &= c_R(1-\beta u) \\ h/c &= (h/c)_R(1-\varepsilon u) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$\theta = \frac{Ts}{4Gt_R{c_R}^3} \frac{a}{(h/c)_R{}^n} \int_0^{u_T} \frac{du}{(1-\tau u)(1-\beta u)^3(1-\varepsilon u)^n}$$

and

$$m_{\theta_T} = \frac{4Gt_R{c_R}^3}{s} \frac{1}{a/(h/c)_R{}^n} \frac{1}{I_1} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

From equation (12) and (5)

$$\kappa m_\theta = \frac{4Gt_R{c_R}^3}{s} \frac{1}{a/(h/c)_R{}^n} \frac{1}{I_1} \quad . \quad . \quad . \quad . \quad (13)$$

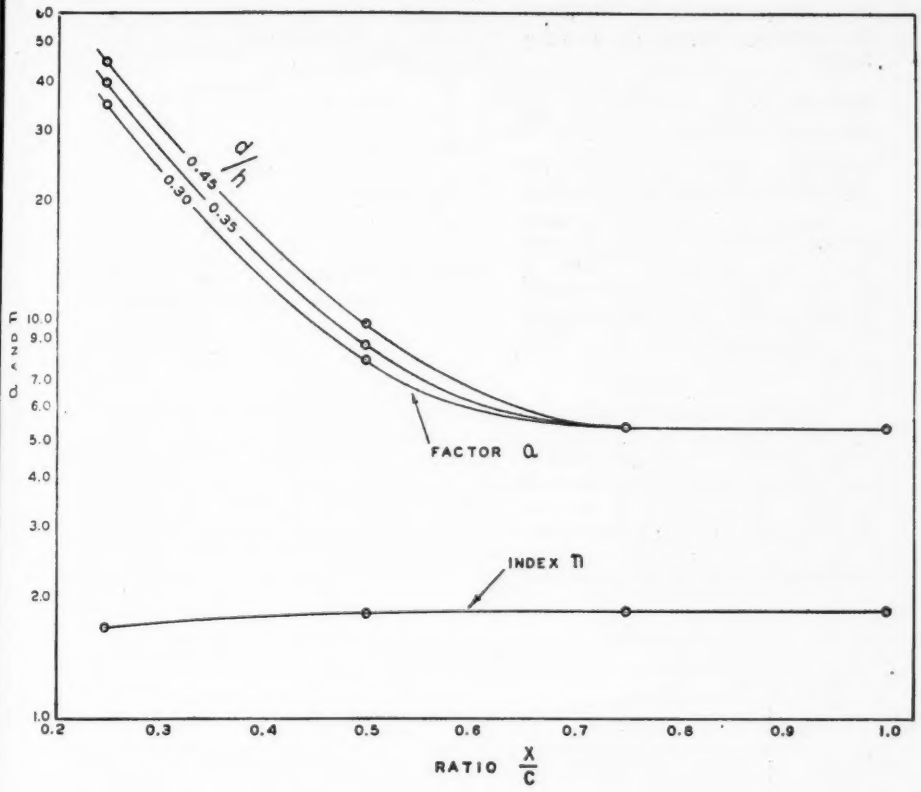

Fig. 4.

Empirical factor a, and index n for the parameter $\frac{\gamma}{\alpha^2} = \frac{a}{(h/c)^n}$.

Reciprocal of the integral I_1 is plotted in Figs. 6, 7 and 8 (for $n=2$), and may be read off if design values of c_T/c_R, $(h/c)_T/(h/c)_R$ and t_T/t_R are known or assigned. Equation (13) provides a direct and simple relation between wing torsional stiffness and skin thickness. Since m_θ can be obtained by means of stiffness criteria[1] and wing weight data[2], equation (13) can be used to estimate skin thickness at an early design stage. It remains only to consider the composite coefficient of m_θ.

3.3 Treatment of the coefficient κ

Obviously it would be most helpful if κ could be constructed from its elements for a given wing, knowing only the general structural configuration. Since at present there is not sufficient quantitative data to do this, and since it would lead to a great deal of complication, it appears simpler to study the elements as a group.

For the sake of clarity, and to indicate approximate orders of magnitude, Table I has been prepared. In this table several of the possible elements of κ are defined, and an approximate range for each (assuming stiffened skin construction) is assigned. It must be borne in mind that these values are only guesses, but if

they are acceptable for argument, the following inequalities are significant:

$$\text{Symmetric twist, } 0.75<\kappa<1.2 \qquad \text{Asymmetric twist, } 0.75<\kappa<1.5 \tag{14}$$

(assuming heavy spars and few stiffeners go together and *vice versa*).

From the foregoing it seems probable that for the case of symmetric twist at least, a study of existing wings should yield a factor or factors for which the variation will be acceptable to design accuracy.

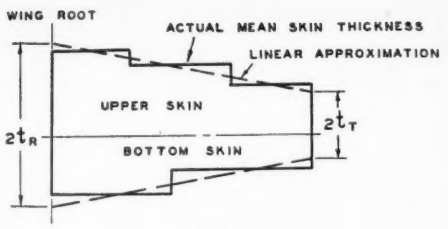

Fig. 5.
Method of obtaining t_R and t_T/t_R from wing data for computing statistical factors.

Since the amount of data on hand is small, it is proposed to deal only with the wing outboard of the root so that k_3 will be assumed zero. On this basis, values of κ have been computed for ten wings, four of which were models made with cellulose acetate, and the results are given in Table II. These results include only the wing outboard of the root, and are based on equation (13) and Figs. 3, 4, 6, 7 and 8. The measured value of m_θ was used in each case, and an equivalent value of t_R was estimated, where necessary, by the method indicted in Fig. 5. The units adopted are m_θ lb. ft./rad., s ft., c_R ft., t in. and G lb./in.^{2}.

TABLE I

Element	*Significance*	*Approximate range*	*Remarks*
k_{10}	Validity of simple torsion formula	0.95—1.10	May include one or all of: Root stress system, re-entrant stress concentrations, taper, etc.
k_{11}	Method of jointing	1.0 0.97—1.0 0.95—1.0	Welding Adhesive Riveting
k_{12}	Root restraint	1.0 0.90	Encastré Overhang of torsion cell
k_{13}	Skin effectiveness	1.0	No buckling
k_{14}	Ribs or diaphragms	1.0 1.10	Widely spaced, poor restraint Closely spaced, fixed edge restraint
k_{15}	Cut-outs	1.0 0.95—1.05	Very small, few Fairly large—restoration of stiffness attempted
k_{20}	Spars	0.05 0.20	Light spars, stressed skin Heavy spars, stressed skin
k_{21}	Stringers	0.02 0.10	Light, wide spacing Closely spaced
k_3	$m_{\theta_0}/m_{\theta_1}$	0 to 0.02 0 to 0.25	Symmetric twist Asymmetric twist, continuous spars

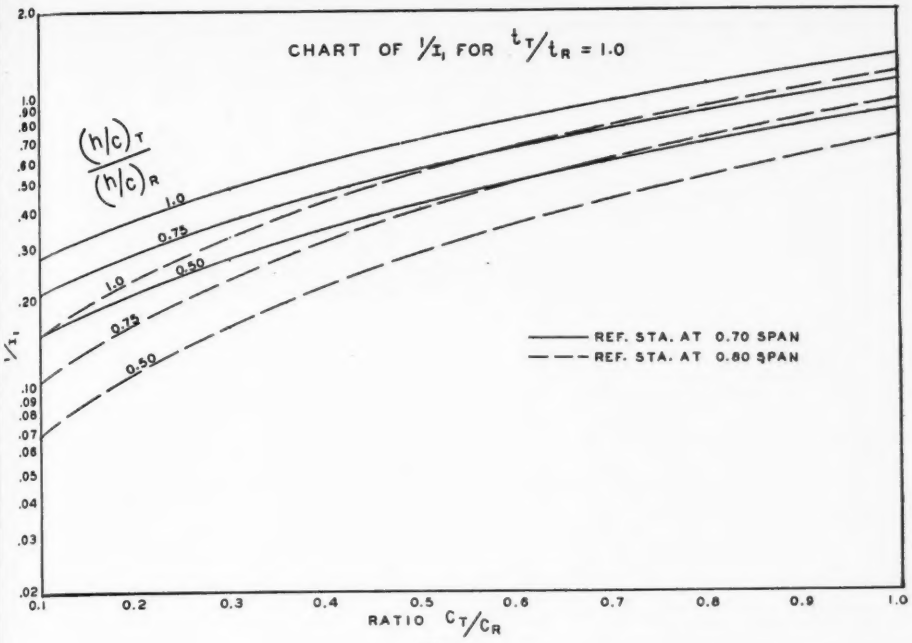
CHART OF 1/I1 FOR tT/tR = 1.0
(h/c)T / (h/c)R
1.0
0.75
1.0
0.50
0.75
0.50
REF. STA. AT 0.70 SPAN
REF. STA. AT 0.80 SPAN
1/I1
RATIO CT/CR

Fig. 6.

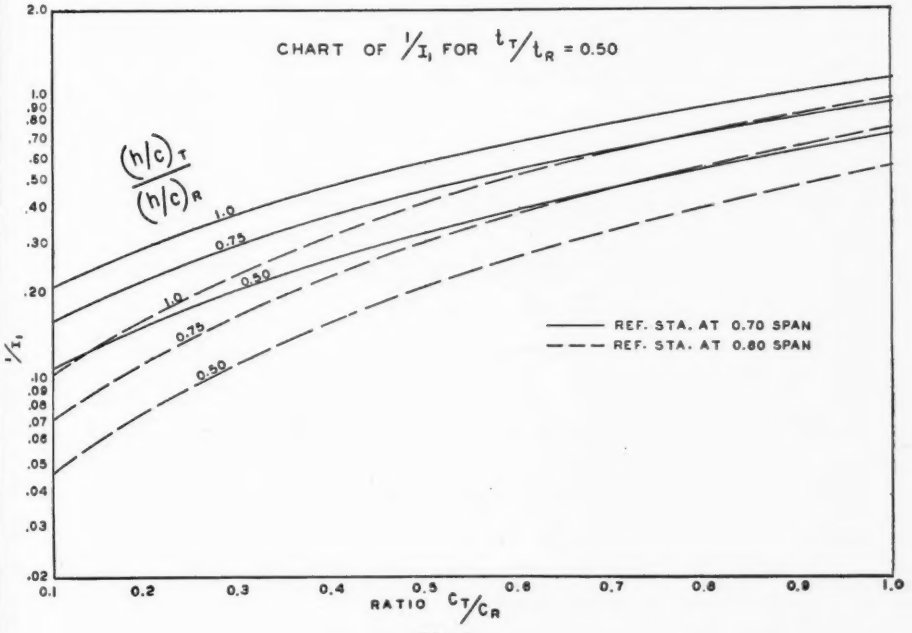
CHART OF 1/I1 FOR tT/tR = 0.50
(h/c)T / (h/c)R
1.0
0.75
1.0
0.50
0.75
0.50
REF. STA. AT 0.70 SPAN
REF. STA. AT 0.80 SPAN
1/I1
RATIO CT/CR

Fig. 7.

TABLE II

Wing	*s* ft.	c_T/c_R	$(h/c)_T/(h/c)_R$	x/c	d/c	t_R equivalent	t_T/t_R equivalent	*Material*	G lb/in^2	κ	*Remarks*
1 2	3.58 3.58	1.0 0.52	1.0 1.0	1.0 1.0	0.40 0.40	0.032 0.032	1.0 1.0	Cellulose Acetate	64,500	0.90 0.83	No spar. Closely spaced ribs, continuous peripheral bond.
3 4	3.58 3.58	1.0 0.76	1.0 1.0	1.0 1.0	0.40 0.40	0.032 0.032	1.0 1.0	Cellulose Acetate	64,500	0.78 0.92	Spar at 65 per cent. chord dividing profile into two cells. Closely spaced ribs.
5	15.15	0.54	0.83	0.29	0.30	0.036	1.0	Dural and Fabric	3.9×10^6	0.89	Overhang of torsionally weak (fabric covered) section. Shear web 0.08 in. tapered to 0.04 in.
6	18.3	0.31	0.64	0.82	0.40	0.048	1.0	Dural	3.9×10^6	0.83	Shear web and angle booms approx. 0.07 in. tapered to 0.05 in.
7	26.0	0.28	0.87	0.73	0.35	0.028	0.80	Dural	3.9×10^6	0.95	Includes wheel well and engine mount. Shear web 0.036 in. tapered to 0.022 in.
8	33.0	0.33	0.63	0.62	0.40	0.039	0.55	Dural	3.9×10^6	0.61	Heavy spars. Extruded spar caps and stiffened webs.
9	15.5	0.54	0.80	0.60	0.35	0.021	1.0	Dural	3.9×10^6	0.93	Overall light construction. Peripheral root attachment spar webs 0.05 in. Small cut-outs.
10	17.8	0.54	1.0	0.59	0.29	0.062	0.53	Dural	3.9×10^6	0.89	Plain wing and well stiffened skin. Shear webs approx. 0.05 in.

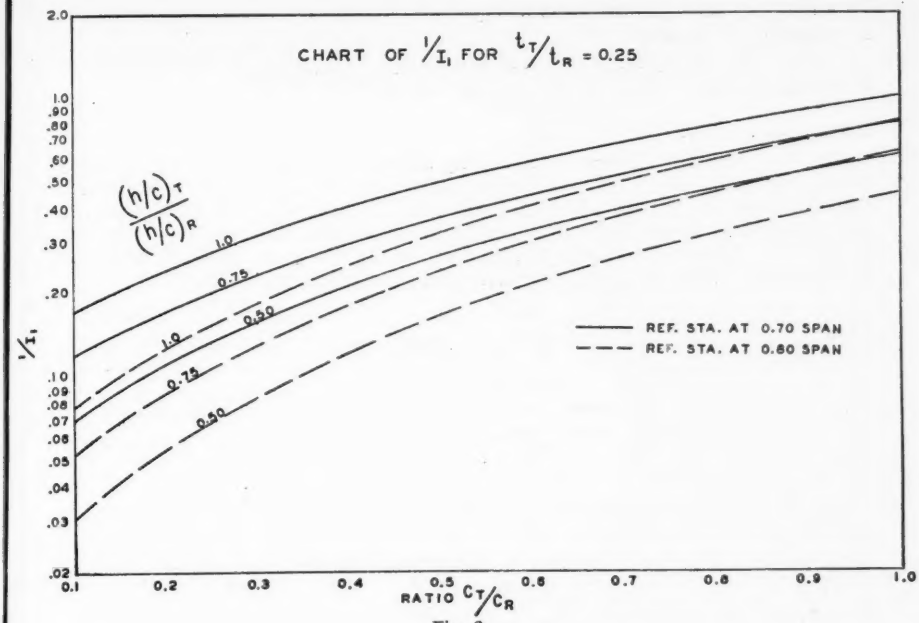

Fig. 8.

Table I indicates that, for a start, κ can be broken into two coefficients, one constant and one varying with type of spar. Hence it is possible to write

$$\kappa = \frac{1 - \Sigma k_{2j}}{\Pi k_{1i}} = K\lambda, \qquad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

where

$$\lambda = 1 - \Sigma k_{2j}$$

$$K = 1/\Pi k_{1i},$$

and tentatively to assign the following values

$$\left.\begin{aligned} K &= 0.90 \\ \lambda &= 1.0 \text{ for light spars} \\ &= 0.95 \text{ for medium spars} \\ &= 0.72 \text{ for heavy spars.} \end{aligned}\right\} \qquad . \quad . \quad . \quad (16)$$

3.4 Recapitulation of the formula

To summarise then, for t_R in inches and G in lb./in.^{2}, equation (13) may be written

$$t_R = 0.187\lambda \cdot \frac{m_\theta S}{G c_R^3} \cdot \frac{a}{(h/c)_R^n} \cdot \frac{1}{1/I_1} \qquad . \quad . \quad . \quad . \quad (17)$$

or for dural wings

$$t_R = 4.8 \times 10^{-8} \lambda \cdot \frac{m_\theta S}{c_R^3} \cdot \frac{a}{(h/c)_R^n} \cdot \frac{1}{1/I_1} \qquad . \quad . \quad . \quad . \quad (18)$$

where m_θ (lb. ft./rad.) is obtained from wing weight data and stiffness criteria[1] [2].

$a/(h/c)_R^n$ and $1/I_1$ are found in Figs. 3, 4, 6, 7 and 8. λ is selected, tentatively as suggested in equations (16).

The scope of equation (18) and how simply it operates is indicated by the following example.

Illustrative example

From preliminary design data, a wing is to have a semi-span (root to tip) of 20 ft., with plan taper of 0.50. The root chord is 10 ft. and a spar at 0.70 chord will clear flaps and aileron. A 15 per cent. thick aerofoil section will be used at the root, tapered to 10 per cent. at the tip, with maximum thickness at 40 per cent. chord. The stiffness criteria require that m_θ be not less than 1,000,000 lb. ft./rad. at 0.70 span. What uniform dural skin thickness will be required?

$$s = 20$$
$$c_R^3 = 1{,}000$$
$$c_T/c_R = 0.50$$
$$(h/c)_R = 0.15$$
$$\frac{(h/c)_T}{(h/c)_R} = 0.67.$$

Since $x/c = 0.70$, from Figs. 3 or 4, $a/(h/c)_R^n = 205$.

By interpolation from Fig. 6, $1/I_1 = 0.54$.

If the bending material is distributed in stiffeners and light angle booms, λ can be taken as 1.0.

By equation (18),

$$t = 4.8 \times 10^{-8} \times 1.0 \times \frac{1{,}000{,}000 \times 20}{1{,}000} \times \frac{205}{0.54} = 0.036 \text{ in.}$$

If it is desired to taper the skin, values of thickness at the root for any desired skin taper can be obtained by interpolation of Figs. 6, 7 and 8. The calculated thickness is the mean peripheral thickness and can be distributed in chordwise steps, provided that reasonable variations are observed.

4. REMARKS

It is interesting to note that some 30 per cent. of the trailing edge can be removed without loss to the wing torsional stiffness. Also, as shown in Fig. 3, the thin high-speed wing suffers two-fold. First, in going to a thin section, there is a loss in stiffness varying at slightly less than the square of the thickness ratio. Second, comparing two wings, identical except that the maximum thicknesses are at 30 and 45 per cent. of the chord, the latter will have a stiffness about 10 per cent. less than the former when the aft shear web is at 0.60 chord, and this margin increases to 20 per cent. for the shear web at 0.50 chord.

Shortcomings of the proposed formula are demonstrated by the example which has been included. The chief difficulty at present is in determining the value of λ to use, and if this can be more rigidly defined, it should be possible to establish an accuracy better than ten per cent. The advantage of the approach used is that the coefficient κ automatically covers inaccuracy of the simple analytical solution. If a systematic check on a large number of existing wings could be made, κ might be broken down in greater detail to improve the accuracy further. In addition, the case of asymmetric twist has yet to be studied.

REFERENCES

1. Ministry of Supply Air Publication 970.
2. CARREYETTE, J. F. Aircraft Wing Weight Estimation. *Aircraft Engineering*, Vol. 22, No. 251, January 1950.

AIRCRAFT RIVETING*

by

H. GIDDINGS, A.F.R.Ae.S., A.M.I.Mech.E.

INTRODUCTION

Many engineers probably regard riveted joints as a very elementary feature of construction, worthy only of a passing reference in a first year Engineering Course, or a page or so in the appropriate "Handbook".

In fact, modern aircraft riveting is an extremely complex subject.

Although the early aircraft engineers inherited an already well-established process from the older branches of engineering, it is surprising, even now, the variety and rapidity of development taking place in this field, and the extent to which such processes still form the principal method of aircraft construction.

Also, as in so many other cases, aircraft engineering makes exceptionally heavy demands upon the process, and current trends are presenting such difficult problems that in some quarters alternative processes (*e.g.* metal adhesives) are being developed.

The author is chiefly concerned with riveting from the standpoint of the Structural Designer, and that side of the picture may seem to be over-emphasised. The overwhelming preponderance of aluminium alloy structures in use in the Industry is the excuse for concentrating on rivets in that type of material.

The functions of the riveted joint in the modern aircraft will be reviewed generally, and some aspects of rivet materials and rivet manufacture will be dealt with briefly.

The various types of rivet in current use are described, and the author's personal assessment of their characteristics and fields of applicability is given.

Some theoretical and test data on strengths are presented, and fatigue and repeated loading characteristics are described.

In addition to the more common strength considerations, some recent work in connection with the special problems of sealing and smooth finish is described. To complete the survey, considerations of rivet weights, and riveting economics are also discussed.

1. FUNCTIONS OF RIVETED JOINT

The main function of the aircraft riveted joint is a structural one, the transmission of load from one structural element to another.

In carrying out this primary function the joint often has to satisfy subsidiary requirements; it has to provide a satisfactory aerodynamic, weather, pressurisation or fuel seal, and also to provide an acceptable finish in relation to aerodynamic or aesthetic standards.

It is obvious that the continuing trend of larger, faster, higher flying, and more efficient aircraft, means increasing severity in the above requirements.

Larger, faster, and more efficient aircraft mean higher loads, stronger and thicker materials to be joined. Efficiency may mean laminar flow surfaces with very high standards of smoothness, equally necessary when high subsonic or supersonic speeds are involved. High altitude means pressurisation with resulting structural and sealing demands upon the riveted joints.

A number of factors have combined to make the use of integral fuel tanks fashionable, again with resulting demands upon sealing.

1.1. LOADS TO BE CARRIED

1.1.1. *Static loads*

The riveted joint may have to provide continuity in a member carrying tensile,

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*A Section Lecture delivered on 24th October 1950 and the 806th Lecture to be read before the Society.

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compressive, or shear loads, usually only in the plane normal to the rivet axis. From the point of view of the rivet all have the same actions, *i.e.* shear and bearing, and the usual loading parameter is taken as the load per inch length of the joint, P lb./in. If the material is fully stressed to an allowable f lb./in.^{2} and a plate thickness of t in. then

$$P=ft \quad . \quad . \quad (1)$$

With modern aluminium alloy materials ultimate tensile stresses as high as 70,000 lb./in.^{2} may be used from purely static considerations, and the limit has probably not yet been reached.

Sheet thickness of 3/16 in. are already in fairly common use, and there are new projects necessitating thicknesses of double this amount. Thus joints in aluminium alloy sheet materials are already requiring strengths in excess of 20,000 lb./in.

A more direct appreciation of the static loads that have to be dealt with by a riveted skin joint, may be obtained from the following simple formula which is appropriate to the skin of a conventional type wing structure at the wing root.

$$P=0.007\ (NwAs)/(t/c) \quad . \quad . \quad (2)$$

where

N = Ultimate design inertia factor
s = Wing semi-span ft.
w = Wing loading lb./ft.^{2}
t/c = Wing section thickness—chord ratio
A = Wing Aspect ratio

Thus for a medium size civil aircraft of, say 120,000 lb. all-up weight,

$N=4.5$
$s=70$
$w=55$
$t/c=0.18$
$A=10.0$

and from (2)

$P=6{,}600$ lb./in.

and it will be noted that for otherwise similar aircraft, P increases directly with increase of span, and also with decrease of wing thickness chord ratio.

Another important case of static loading is met in pressurised fuselages. If the operating pressure differential is p lb./in.^{2}, the fuselage cross-sectional radius is r in. and the static safety factor is F then

$$P=Fpr \quad . \quad . \quad (3)$$

For an aircraft flying at 40,000 ft. with cabin pressurised to maintain 5,000 ft. altitude conditions, and the required minimum static factor of safety of 2.0, $p=9.5$ lb./in.^{2} and a fairly large fuselage with $r=100$ in., then from (3) $P=1{,}900$ lb./in. More will be said about this later.

Loads in the direction along the rivet axis, putting the rivet itself in tension, are fortunately usually small, although nearly always present from direct aerodynamic suction or internal pressurisation sources. They seldom exceed a value of some 30 lb. per inch length of joint.

1.1.2. *Repeated loads*

The most important case of repeated loading encountered by the author so far, is provided by the pressurised fuselage of a large high altitude civil aircraft.

For every flight the fuselage pressure differential starts at zero, is raised to the operating pressure differential "P", and returns to zero at the end of flight. Pressurisation ground checks have also to be considered. Considering a life of some 10 years, or in the region of 30,000 flying hours, approximately 5,000 pressurisation cycles are possible.

As a test requirement a "life factor" of 2.0 has been included, and a test of zero to operating pressure for 10^4 cycles has been specified. Other cases of repeated loading arise, such as repeated manoeuvring of military aircraft to moderate "g". For this condition a test requirement of 500 repetitions of 3/4 maximum positive "g" has been suggested, but is normally not likely to prove critical.

1.1.3. *Fatigue loads*

Most people will be aware that aircraft engines, particularly the reciprocating variety, are not perfectly balanced items of machinery. In practice the local aircraft structure has to be isolated from, or immunised against, high frequency vibrations of various engine or propeller orders, and amplitudes which can only be determined by careful tests in each particular case. Not so often appreciated is the fact that load fluctuation in aircraft primary structures, excited by atmospheric turbulence, is rapidly becoming an important fatigue consideration in civil aircraft. It has been shown in flight tests that most aircraft primary surfaces (wings, tail planes) are

oscillating in flight the whole time, mainly in the fundamental flexural mode, and that for a large proportion of the time the amplitudes are significant from the fatigue point of view.

Pugsley was responsible for a test requirement proposal for a life of 3/4 the aircraft flight life at the steady flight stress and an amplitude of ±10 per cent. of that steady stress.

These current tendencies are making this condition more important:—

(*a*) The increasing life required from expensive civil aircraft for economic reasons.

(*b*) More precise design to lower factors, giving rise to increased steady flight stresses.

(*c*) The use of structural materials of very high static strength to give the same strength in terms of "*g*", also therefore increasing steady flight stresses.

Taking a fairly typical frequency of 5 c.p.s. and a total life of 30,000 hours, also an ultimate stress of 50,000 lb./sq. in. in aluminium alloy associated with a factor of 3½, then Pugsley's suggestion, interpreted precisely, gives a stress cycle of 13,300 ± 1,330 lb./in.² for a life of 400×10^6 cycles. Actually a life of 100×10^6 cycles was at one time considered adequate to demonstrate safety.

Criticisms of this suggestion have been made on the grounds that it is not severe enough, and also that the time taken to make the test is impracticably large with current test techniques, of the order of a month for each test. A more recent suggestion has called for a life of 2×10^6 stress cycles of level flight stress ±7½ per cent. of ultimate stress, *i.e.* 13,300 ± 3,700 lb./in.² in the example previously quoted.

1.2. Materials to be joined

Steel as an aircraft structural material is not popular nowadays and its use is confined mainly to small fittings. At the present time aluminium alloys are almost universally favoured for primary structures, and the only prospect of immediate challenge comes from the new high strength magnesium zirconium alloys. Riveting problems, therefore, are almost entirely confined to the following aluminium alloy materials:—

Specification	*Ult. tens. strength lb./in.²*
DTD.610	56,000
DTD.546	60,480
DTD.687	72,000

The variants of these, unclad and close tolerance versions, give slightly better properties but not significantly different from our point of view.

For comparison the magnesium zirconium figures are as follows:—

DTD.626	38,000

The present range of thicknesses of aluminium alloy sheet in use is from 30 SWG (0.012 in.) to about 3/16 in., but the next generation of aircraft will probably see this upper limit doubled.

2. RIVET MATERIALS

The basic problem in a rivet material is to achieve maximum possible strength with the greatest ease of setting. Unfortunately, these properties are directly coupled, hardness and setting difficulty increasing with increasing strength.

Thus the ratio

$$\frac{\text{ultimate stress T/in.}^2}{\text{Vickers Pyramid Hardness No.}}$$

is approximately constant for most materials, its values being approximately

Mild Steel	0.21
Aluminium Alloys	0.19

The other criterion of setting suitability—permissible elongation—also tends to be reduced with increasing strength, in both aluminium alloy and steel materials. Generally speaking steel materials show a slight advantage from both points of view.

It will be shown later that for riveting efficiency, a rivet material of at least equivalent strength properties to the sheet material is required. Aluminium alloy materials usually derive their strength from a combination of a solution heat treatment and artificial or natural ageing process. The strongest sheet materials (DTD.546 and DTD.687 types) derive their strength from both solution treatment and artificial ageing. Unfortunately, equivalent rivet materials cannot be set in the fully aged condition. Obviously, therefore, unless artificial ageing of the rivets is resorted to after setting, the equivalent rivet materials to these alloys will

not develop the same strength; of course, the artificial ageing of a complete Brabazon wing is a little fantastic!

The strength of an aluminium rivet material in the full naturally aged condition therefore is all that can be obtained. This involves setting at a very early stage in the ageing process, otherwise setting difficulties, including cracking, occur.

Figure 1 shows the principal aluminium alloy rivet materials in order of increasing strength.

L.36 is the almost pure aluminium rivet, and may be dismissed from the structural point of view.

DTD.303 is the 5 per cent. magnesium alloy Mg.5 of relatively low strength and is set as received. It is fairly popular in the low strength field and is also recommended for use in magnesium alloy structures. Its electrical potential is satisfactorily nearer that of magnesium than other rivet materials, and tropical corrosion tests have shown it to be satisfactory.

DTD.327 is the universally popular 2 per cent. copper type alloy similar to the American 16-ST. It is solutionised in bulk before delivery and may be set satisfactorily in the full, naturally aged, condition. Shear strength is moderate, developing about 32,000 lb./in.² as riveted, and bearing strength is equal to that of DTD.610 type sheet material.

The most popular high strength rivet alloy is the straight Dural 17 ST type of L.37 specification. There is a production complication in that it has to be set in the freshly solutionised condition, before naturally ageing, as in the latter condition it is too hard to rivet. Fig. 2 shows the naturally ageing characteristics, and the usual requirement is to set within two hours of quenching. The onset of age-hardening can be delayed by refrigeration; for example, if rivets are stored at 0, −5°C., they may be used up to 45 hours, or if at −15, −20°C., up to 150 hours after quenching, but they must still be set within two hours of emergence from cold storage. Set under these conditions and after the full natural ageing period, bearing strength is adequate for use in DTD.546 type sheet and shear strength as riveted is approximately 36,000 lb./in.².

DTD.404 is the 7 per cent. magnesium alloy Mg.7, and has high strength derived

MATERIAL			MIN. SPEC. f_t / 2 TONS/IN	ULT. SHEAR STRESS TONS/IN²	HEAT TREATMENT CONDITION	
SPEC. No.	COMM^L NAME	ALLOY TYPE			WHEN PLACED	ULTIMATELY.
L 36	NORAL 2S	98% AL.	7	4·8	AS RECEIVED	AS RECEIVED
DTD303	MG 5	4½-5½% MG.	16 – 21	12·8	AS RECEIVED	AS RECEIVED
DTD327	NORAL 16 ST.	1½-3% CU.	17	14·8	SOLUTIONISED & NAT. AGED	SOLUTIONISED & NAT. AGED
L 37	NORAL 17 ST.	3½-4½% CU.	25	16·2	FRESHLY SOLUTIONISED.	SOLUTIONISED & NAT. AGED.
DTD404	MG 7	6½-10% MG.	27	17·5	AS RECEIVED	AS RECEIVED
DTD683 ALLOY	M 75S	COMPLEX, MEDIUM ZN-CU-MG CONTENT	25	15·6	FRESHLY SOLUTIONISED	SOLUTIONISED & NAT. AGED
			29	18·5		SOL^ND & AGED AT 100°C – 24 HRS.
DTD363 ALLOY	C 77S	COMPLEX, HIGH ZN-CU-MG CONTENT	29	17·8	FRESHLY SOLUTIONISED	SOLUTIONISED & NAT. AGED.
			34	21·2		SOL^ND & AGED AT 100°C FOR 24 HRS.

Fig. 1.
Aluminium alloy rivet materials.

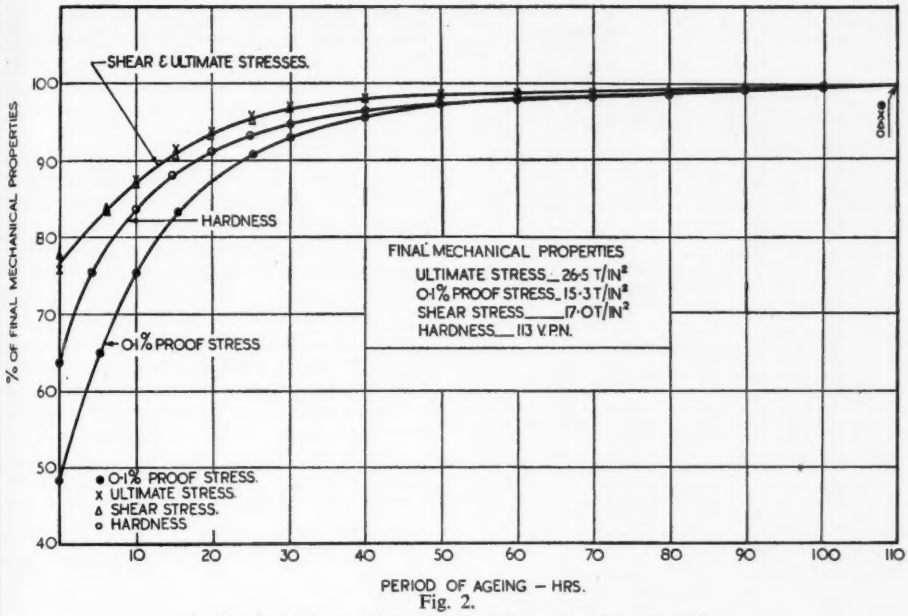


Fig. 2.
Age hardening curves for L.37 aluminium alloy rivet material.

from cold work but is suspect, in that it is prone to cracking.

Experiments have been made with the very high strength complex Zn-Cu-Mg alloys of DTD.683 and DTD.363 compositions, corresponding to the American types M.75S and C.77S respectively. The hope was that there might be a small bonus of strength to be utilised in the full naturally aged condition, the rivet being set freshly solutionised on a similar sort of basis to that already described for the L.37 material. After tests, however, the conclusion was that the small gain in strength was not worth the difficulty of setting such hard materials. The artificial ageing process is needed to achieve the full potentialities of the materials, and this is impracticable for most riveted structures.

3. RIVET MANUFACTURING PROCESSES

Rivets are manufactured from drawn or extruded wire or bar, and in the case of some tubular rivets, from sheet materials, by forging or machining, or in the latter case by pressing processes. Rivets made from drawn wire usually give better results than those from extruded bar or wire used, in some cases, for the larger diameter rivets. The latter material is apt to have much coarser grain structure and increased liability to splitting, as well as lower strength, than the drawn wire.

The forged rivet ideally gives better grain flow than the machined type and may be preferred. In practice, machined rivets give satisfactory results, although they are more expensive than the former.

Close tolerance countersunk head rivets are difficult to produce by forging, but a recently developed compromise first of all forges the rivet and then machines the head only. Tolerances are satisfactory and the reduction in cost is significant.

4. CHARACTERISTICS OF DIFFERENT TYPES OF RIVET AND SETTING PROCESSES

4.1 General

Rivets may be conveniently classified as solid, semi-tubular, and tubular types.

Within each of these groups are the different types of preformed head, of which the principal ones are the mushroom, snap and

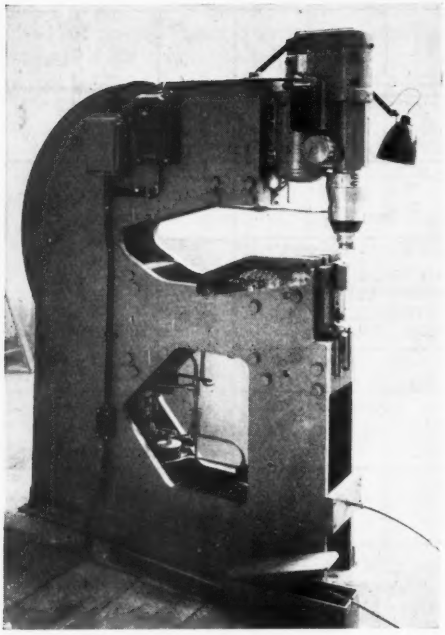


Fig. 3.
Spin dimpling machine.

countersunk varieties. The rivets are set in drilled or punched holes, which for structural or sealing purposes at least, should be controlled to reasonably close limits.

For the countersunk head types, the hole may be cut countersunk up to a D/t ratio of about $2\frac{1}{2}$ for the 120° head. Above this ratio the countersink should be formed by dimpling.

4.2. Methods of sheet preparation

Holes are normally drilled and because of the expansion of most rivets in the setting operation, tight tolerances are not necessary.

For structural joints some control is desirable, and it is the practice of the Bristol Aeroplane Company to use a "controlled tolerance" hole achieved by the simple process of drilling slightly under size and then drilling out dead to size with a final skimming operation.

Where a good flush finish is required it is important that the axis of the hole be normal to the sheet face, and a drill guide is used if the sheet is thick. The countersink is very important, both from the point of view of depth and angle, and also in getting the axis normal to the sheet face. The Bristol Aeroplane Company uses specially ground and set cut-countersinking attachments driven by the usual power tools, which control all of these features.

Where dimpling is required two classes of finish are provided, the normal tolerance dimple, and the close tolerance variety. The former is satisfactory from the strength point of view, is used with normal tolerance rivets, and is formed by simple punch and die in any "squeezer". The finish is poor, particularly with high strength sheet.

The close tolerance dimple is associated with the close tolerance rivet and is only used where a high standard of flush finish is required, *e.g.* on wing skins forward of the rear spar. The Bristol Aeroplane Company has put considerable development recently into the production of this class of dimple and two methods have been developed:

(*a*) "Hot dimpling" by electrical resistance heating of the sheet locally, using a converted spot welding machine. Male and female bronze dies are screwed into the electrode stalks, and the ordinary heat and pressure cycle of the spot-welder, suitably modified, is applied to the sheet.

The same scrupulous cleanliness as for successful spot welding is required and only a full chrome-sulphuric acid or hydro-fluosilicic pickle will achieve it. Constant attention to dies to minimise pick up and wear is also necessary.

(*b*) "Spin dimpling," again using male and female solid stellite dies and pressure on the sheet. In this case, the male die consists of a two-bladed revolving coining tool which spins the sheet into the female die. There is no cutting action and a light machine oil is used as a lubricant. The heat generated by friction is very small and the process is essentially a cold forming one. Special power-operated machines have been developed to carry out this process in production and one is shown in Fig. 3.

Both of these processes produce accurate dimples in high strength sheet which are indistinguishable externally from a good cut countersink. Metallurgical and structural fatigue tests to check these aspects of the dimples have been made with satisfactory results.

In production, however, the Company prefers the spin-dimpling method, and this is now in general use.

A comparison of a normal dimple with a hot formed dimple is shown in the macro-section on Fig. 4.

4.3 Solid Rivets

The standard S.B.A.C. range covers these in all the normal materials and head shapes, with normal rivet tolerances, and also in the "close tolerance" type. Fig. 5 shows the standard proportions.

The maximum size of aluminium alloy rivets in use is 1/2 in. diameter. The largest that has been used on the Brabazon is 3/8 in. diameter and even this has been exceedingly difficult to set.

The great majority of primary structural joints use solid rivets, and in these days of flush finishes, mostly the countersunk type head. The normal tolerance rivet is satisfactory from the structural point of view but when good finish is required then the close tolerance rivet is used.

A comparatively recent innovation is the "domed countersunk" type head. This is a normally proportioned countersunk head with the addition of a "few thou'" dome, which increases the efficiency of driving, at the same time minimising damage to the skin.

The countersunk head rivet also exists in a variety of included head angles between 60° and 120°.

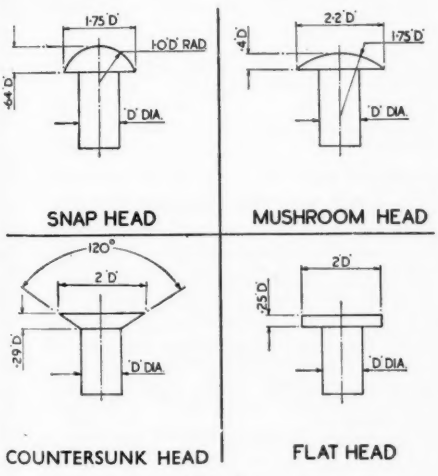


Fig. 5.
Solid rivet proportions.

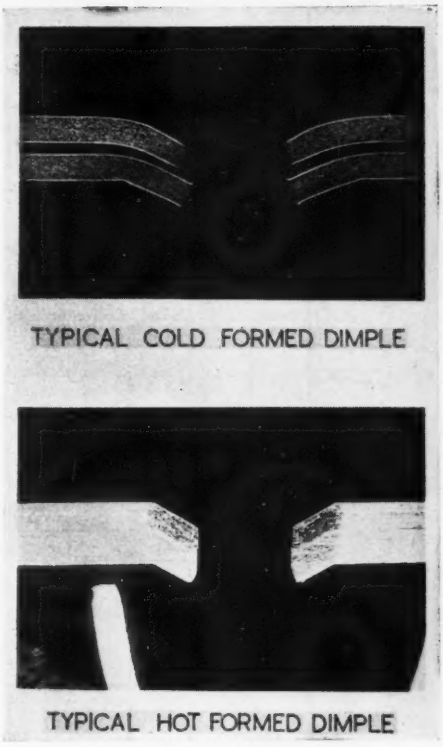


Fig. 4.
Skin dimpling. Comparison of dimples by macro-sections.

The smaller angle heads generally cause less skin distortion in setting, and also pay a slight dividend in strength. At Bristol, in common it is believed with most British firms, the 120° head has been standardised, but American standard practice uses the 100° type. There is at present a move in Great Britain to go over to the 100° head to line up with the Americans.

In the interests of standardisation again, in addition to the 120° countersunk head, the Bristol Aeroplane Company uses the snap head on internal structure, and the mush-room head on external surfaces where a flush finish is not required.

The tails of the rivets are set flat in the interest of setting speed, and tests have been made to determine the minimum protrusion required. This length has to be kept down, not only to minimise the amount of driving

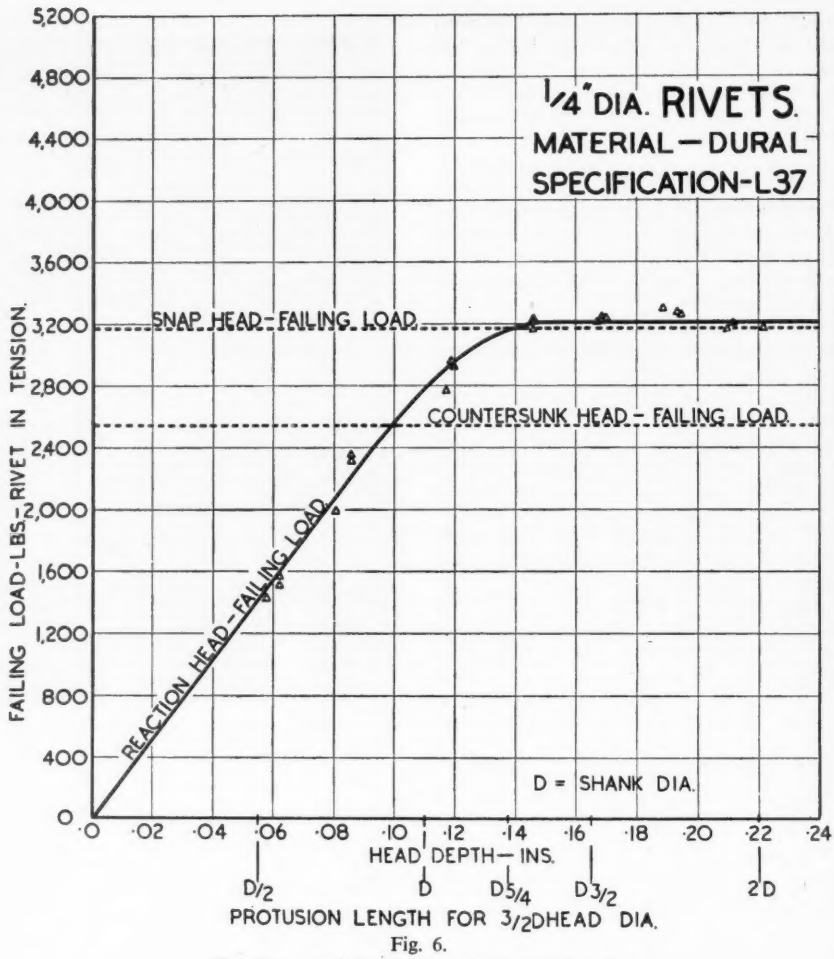


Fig. 6.
Tensile strength in relation to protrusion length.

necessary and therefore improve finish and reduce cost, but also to keep the rivet weight at a minimum.

Tests determined two things (1) that the tail should be set to a diameter of at least 3/2 D. in order to achieve maximum shear strength, and (2) that an initial protrusion length of $1\frac{1}{4}$ D. set to the above diameter, is all that is necessary to develop the full tensile strength of the rivet. These results are shown on Fig. 6.

4.3.1 *Methods of setting solid rivets*

Methods of setting ordinary solid rivets are at present very varied, ranging from the primitive hand-held hammer and dolly, to completely automatic machine setting.

In the final assembly jigs the conventional pneumatic hammer and hand-held dolly are still used at Bristol, and even the hand hammer in a few awkward places. In the interests of finish the "percussion" method, where the tail is hit by the hammer, is preferred to the "reaction" method where the preformed head is struck and the tail formed by the dolly.

Wherever possible the Company much prefers squeeze riveting to the foregoing, believing that such methods give more consistent and better results, both in terms of

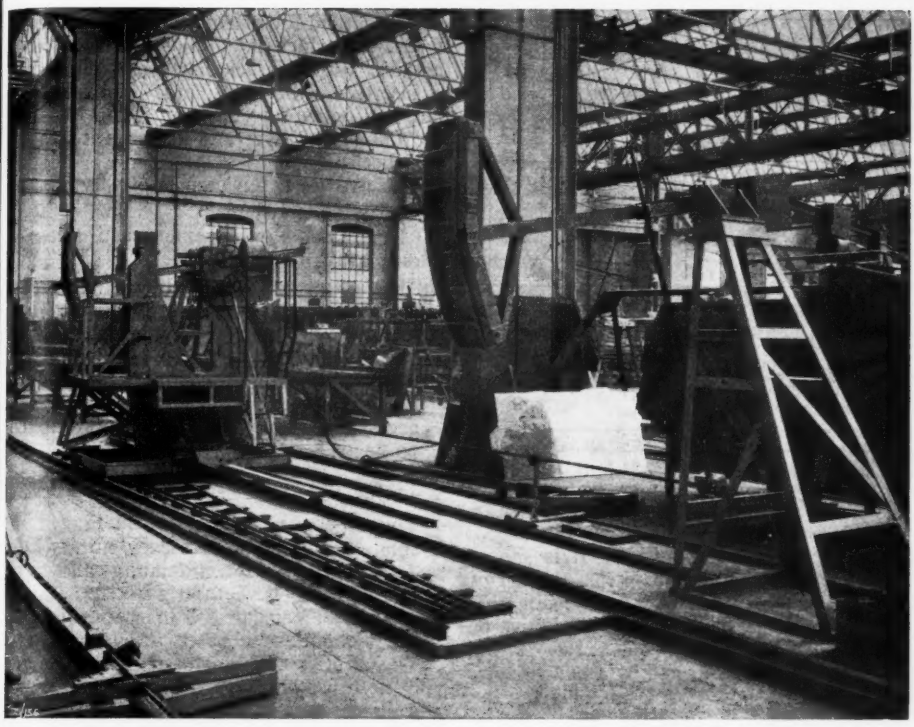


Fig. 7.
Fixed squeeze riveting equipment.

finish and strength, and also time and cost. By such means the setting force is accurately controlled, and the whole force is reacted by the machine and not partially by the structure, as with percussion or reaction riveting.

Many types of squeeze riveter are used, on the bench, pneumatic or hydraulic "alligator" type tools, and also mechanical lever presses.

For large sub-assemblies special pneumatically-operated squeezers are in use, and one is shown in Fig. 7. A proprietary type of machine, imported from America and becoming increasingly popular, is the "Erco" fully automatic squeezer. This may be arranged to do anything from simple squeeze setting of a normally drilled and hand-fed rivet, to automatically punching the hole, feeding the rivet and setting, including dimpling of the sheet in the case of countersunk rivets. This machine takes any standard type rivet, including those in L.37 material. A very satisfactory structural joint is obtained with strength slightly better than with normally set rivets. The flush finish obtained with countersunk head rivets, however, is not of the highest standard, but is satisfactory for low speed aircraft and a not too critical aesthetic standard. Riveting speed is good, and this is the main advantage.

One important implication of machine riveting is the necessity of careful design so that details and sub assemblies may be taken to the machines, and also are matched to the machine limitations. Considerable subdivision of structure is required and jigging must be arranged to suit the process.

Application of machine riveting to a structure designed and jigged conventionally is difficult, and results would hardly justify the effort.

4.4. Semi-tubular riveting

The only example of this type of riveting process which it is proposed to describe is the well-known "Bifurcated" process, for which the Bifurcated and Tubular Rivet Co.

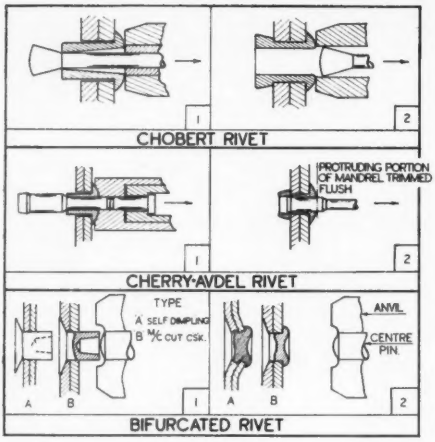


Fig. 8.
Chobert, Cherry, Avdel and Bifurcated riveting processes.

of Aylesbury are responsible. It is shown in Fig. 8 and it will be noted that the tail of the rivet is bored out over the length protruding from the sheet face. The motive of this tubular tail is to ease the setting operation, which is effected by a punch being forced into the bore of the tail, splaying the tube out and over against the sheet.

This rivet has been used in holes prepared in the usual way and the tail set by an ordinary pneumatic gun, with a special tool. Special automatic machines are usually employed, and one is shown in Fig. 9. This machine feeds the rivet into the hole and sets it. It will also dimple the sheet for a countersunk head rivet if required, all in one sequence of operations. A small portable version of this riveting machine which may be held by hand and used in assembly jigs and so on has also been developed. This operates on the "one shot" principle and needs a separately held dolly at the rivet tail.

The rivets are available in aluminium L.36, mild steel, and aluminium alloy DTD.327 materials, and in 3/32 in, 1/8 in. and 3/16 in. diameters. The normal head shapes are all supplied, with the exception of the snap head.

4.5 Tubular rivets

All the tubular rivets which will be described are what the author terms "mandrel setting". A more common term is "blind" rivets, because access to only one side is needed for placing. In all of the four types with which the author is concerned, a mandrel with a larger diameter "tulip" end is inserted in the bore of the rivet from the tail, and pulled into the rivet. This expands the tail of the rivet and clenches it against the sheet.

The two great advantages of this type of process are:

(*a*) Its use for blind riveting when access is only available on one side.

(*b*) The setting action is a self-reacted squeezing operation, a great advantage when riveting very light structures and a good finish is required. Because of this, riveting of this type is used as a portable squeeze riveting process in the assembly jig, not necessarily only when access is prohibited on one side.

4.5.1. *The "Chobert" riveting process*

This type of rivet is shown in Fig. 8. It is sponsored by Aviation Developments Ltd. and is available in aluminium alloys to DTD.327 and L.37, and in steel. Sizes range from 1/8 in. to 3/8 in. diameter, with snap or countersunk heads.

The rivet is manufactured by machining and the process necessitates close tolerances. The bore of the rivet is tapered, being slightly smaller in diameter at the tail, and the rivet is set by drawing a high tensile steel mandrel completely through the bore. If sealing or maximum strength is required, then a sealing pin has to be inserted in the bore after setting. Special guns are available for setting, in manually, pneumatically, or pneumo-hydraulically operated types. For production, repeater type guns are used, where up to about 50 rivets are stored on the mandrel. When empty the mandrel may be instantaneously recharged from the special "cartridges" of rivets supplied.

When sealing pins are fitted the ultimate strength is nearly as good as solid rivets, but Proof strength is not so good. This is principally due to the poor clenching action, and consequent tilting of the rivet under load.

If mandrels are allowed to wear, difficulty is sometimes experienced with poor expansion of the rivet in the hole. Another snag is associated with the sealing pins. Damage is often caused to light structure by their insertion, and a trimming operation is sometimes necessary when complete insertion of the sealing pin cannot be achieved.

Despite these drawbacks the Chobert rivet is extensively used, and while it is not by any means a cheap rivet, its speed in setting is good, particularly if sealing pins are not required.

4.5.2 *The "Avdel" riveting process*

The "Avdel" rivet was developed initially by the Bristol Aeroplane Company and is now manufactured by Aviation Developments Ltd., who also supply specialised setting equipment. It is shown in Fig. 8.

Unlike the "Chobert" system a separate mandrel is supplied with each rivet, being retained in the rivet as a seal after setting. The mandrel has three diameters, the smallest being a loose fit in the bore of the rivet. The intermediate diameter is an interference fit in the rivet bore, while the largest diameter on the end is of such a size that it expands and clenches the tail of the rivet against the sheet. The small end of the mandrel is of sufficient length to be gripped by the setting tool which first draws the intermediate diameter into the rivet, thus expanding the shank tightly into the hole. As the mandrel is further drawn into the rivet, the large diameter clenches the tail on to the sheet. Finally, the mandrel breaks at a notch between the small and intermediate diameters when the required setting load is reached. The protruding part of the mandrel is trimmed, either by simple side cutters or by a rivet milling tool.

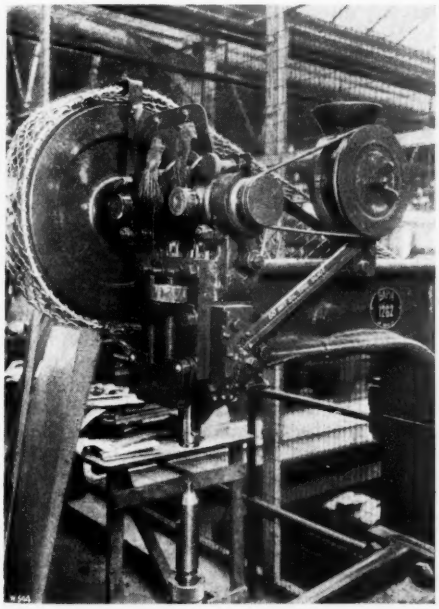


Fig. 9.
Bifurcated automatic riveting machine.

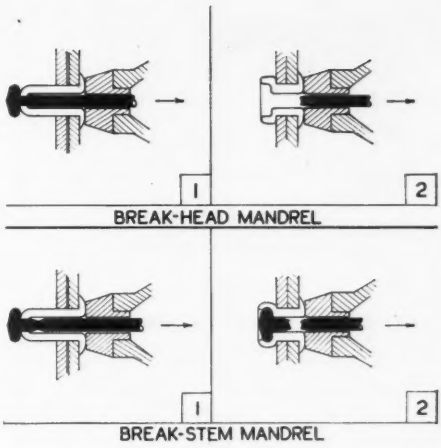


Fig. 10.
"Pop" riveting process.

It will be noted that the system is designed to give both rivet expansion and drawing together of the sheets. The latter action is limited somewhat because the rivet is expanded to a tight fit in the hole before clenching takes place. Good clenching is nevertheless obtained and excellent strength, sealing, and finish.

The rivet is available in aluminium alloy DTD.327 material and with snap or countersunk heads. Development is proceeding to produce the rivet in A-17ST type aluminium alloy. The mandrel is also in aluminium alloy but to DTD.363. This rivet is particularly useful as a portable squeeze riveting process in very light structures, where a tight rivet with good proof strength and fatigue resistance has to be associated with a fine finish. For the latter requirement the countersunk head of the rivet is set slightly proud and then milled off, the rivets then being almost indistinguishable from the sheet. Unfortunately it is an expensive process, and its use has to be restricted to those applications where its special virtues are needed.

Fig. 11.
The Bristol rivet milling tool.

4.5.3. *"Cherry" rivets*

These rivets are of American manufacture and widely used in that country. The "Dollar famine" unfortunately precludes their use here, although the range generally corresponds to various British rivets. Thus, the "self plugging" type corresponds to the "Avdel", while the "pull through" type corresponds to the "Chobert." There is a third type known as the "Regular hollow" type which is similar to the British "Pop" rivet.

The rivets are available in a range of materials, steel, aluminium alloy and Monel, in both countersunk and brazier type heads, and in a size ranging from 1/8 in. to 9/32 in. The A.17ST and steel self-plugging types are extremely useful rivets and show an advantage over the DTD.327 Avdel rivet.

A full range of specialised setting equipment, manually or power operated, is available.

4.5.4. *"Pop" riveting*

This system is shown on Fig. 10 and was designed, it is believed, by Major Wylie of Armstrong Whitworth. The rivets are now manufactured by the Tucker Eyelet Co., and distributed by Aircraft Materials Ltd. Hand and power-operated setting equipment is available. The mandrel is a loose fit in the bore of the rivet and the larger diameter head expands the tail when drawn into it. Tail formation and sheet clenching action are good, but rivet expansion in the hole is poor.

The mandrels can be supplied to break either adjacent to the head (Break-head type) or in the stem within the rivet (Break-stem type). With the former type the heads of the mandrels fall clear, leaving a hollow rivet, while in the latter case the mandrel is usually retained in the rivet and gives some degree of sealing. Unfortunately little increase in strength is achieved and a small percentage of the mandrels fall out, either immediately after setting, or during service. The rivets are available in aluminium alloy (DTD.303 equivalent) and Monel materials, in sizes from 7/64 in. to 0.2 in diameter, and in both snap and countersunk type heads. This rivet is excellent where strength and sealing requirements are not too rigorous, and is very economical and quick in setting. It is very popular, and is widely used in industry outside that of aircraft manufacture. A. V. Roe and Company has sponsored a close tolerance machined version of the standard rivet in a nickel silver material.

The Fairey Aviation Company has developed a tool for counterboring blind holes in thick members such as spar booms. This enables the "Pop" rivet to be used, the tail of the rivet being expanded into the counterbore.

4.6. RIVET MILLING

Demands for a super finish have led to the development of a tool for milling rivet heads flush after setting. The tool developed and used by the Bristol Aeroplane Co. is shown in Fig. 11. It consists of a special end mill attachment for a standard Desoutter pneumatic drill gun, with provision for accurate setting for depth of cut, and swarf removal by air jet. A rubber pressure pad with hardened metal guide bush is also used, the mode of operation being shown in the photograph.

Where a milled finish is consistently required, adjustment has to be made to the depth of countersink, so that the head of the rivet is slightly proud of the skin surface.

5. STRENGTH OF RIVETED JOINTS

5.1. THEORETICAL ASPECTS

While any first year student of structures is familiar with the elementary stressing of a riveted joint, the fundamental implications of the simple theory are probably not so widely appreciated.

Thus an aircraft structural joint has to meet a "proof," as well as the more obvious ultimate strength requirement. At the "Proof" load the deformation of the joint must not be large enough to make the structure "un-airworthy." Assuming that a rivet of at least the equivalent material to the sheet is used, then this "Proof" strength is primarily a function of the allowable bearing stress in the sheet. Thus nothing is gained by using a steel pin or rivet in aluminium alloy sheet, except in special cases.

Let the proof strength of a single rivet $= dt f_B$, and the minimum pitch is usually a constant function of rivet diameter. Pitch $b = Nd$, and in general practice $N = 5.0$ with a minimum of 4.0. From these

$$P = (t/N) f_B \quad . \quad . \quad (4)$$

or for n rows of rivets

$$P \simeq nt (f_B/N) \quad . \quad . \quad (5)$$

Thus the strength of the joint is limited by the sheet only, and is independent of rivet diameter.

The ultimate strength of the rivet is primarily dependent upon the allowable shear stress of the rivet material. Thus ultimate strength of one rivet $= \pi d^2 f_s/4$

and $P \simeq \pi dn f_s/(4N) \quad . \quad . \quad (6)$

for n rows.

The diameter of the rivet does not need to be greater than that necessary to make the

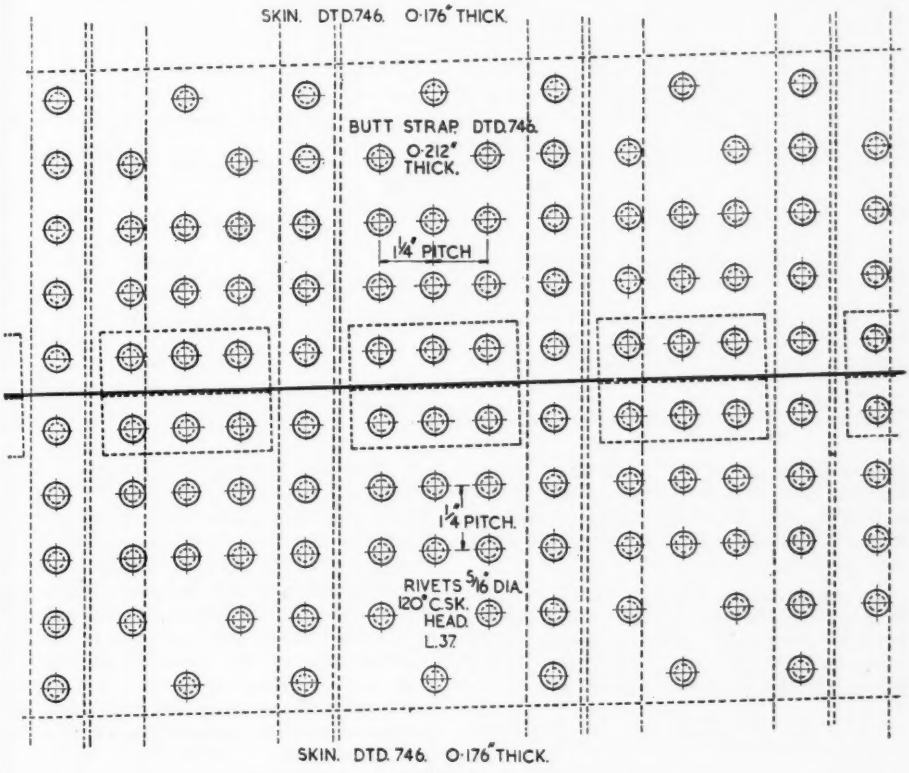


Fig. 12.
Typical inner wing chordwise skin joint on Brabazon.
Design load per inch (tension) = 7,750 lb./in.

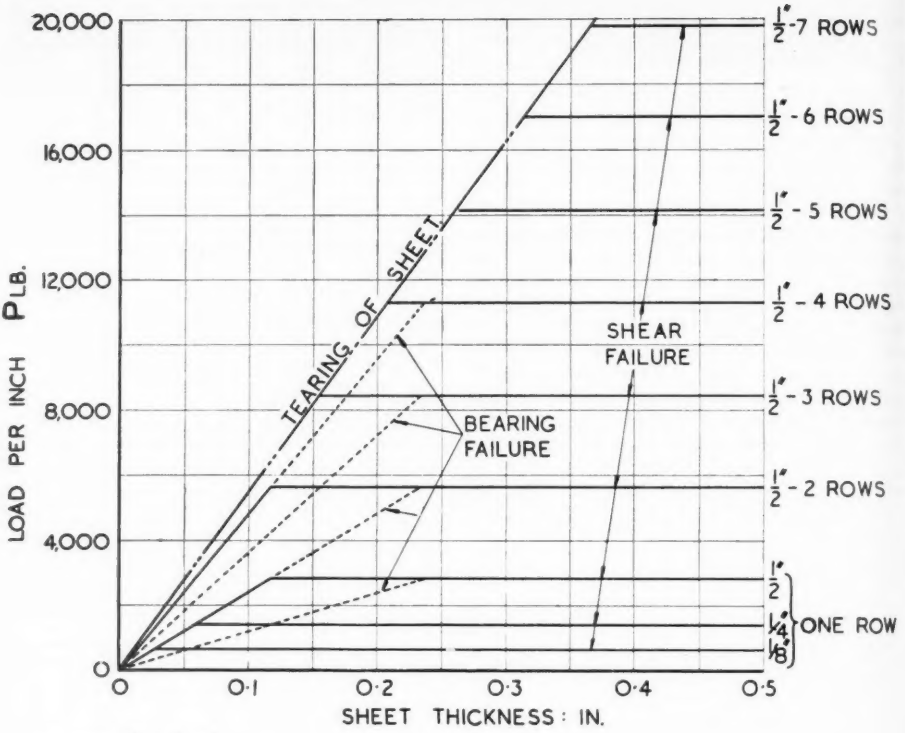


Fig. 13.

Approximate strength of L.37 riveted joints in DTD.546 sheet (Single Shear).

shear strength equal the bearing strength.

From (5) and (6)

$$d/t = 4 f_B/(\pi f_s) \quad . \quad . \quad (7)$$

Nothing is gained by using larger rivets, and for countersunk rivets the use of too large a diameter would lead to a reduction in strength, assuming that minimum pitch is used in each case.

To get an idea of what this means in terms of actual proportions consider some typical modern aluminium alloy materials, L.37 rivets in DTD.546 sheet. The appropriate values are approximately as follows:—

$f_B = 120{,}000$ lb./in.^{2} for snap head rivets

$= 60{,}000$ lb./in.^{2} for countersunk head rivets in cut countersunk holes ($D/t = 2.0 - 2.5$)

$f_s = 36{,}000$ lb./in.^{2}

from (5) $P = nt$ 24,000

and $= nt$ 12,000 . . . (8)

for snap head and countersunk head rivets respectively. The allowable ultimate tensile stress in tension for DTD.546 is 60,000 lb./in.^{2}, and with a multi-row joint an efficiency of 90 per cent. should be achieved.

It follows from (8) that to develop the maximum tensile strength of the material with a single shear joint, at least three rows of snap head or five rows of countersunk head rivets are required.

It also follows from (7) that the rivet diameter should be approximately 4.25 times, or 2.12 times the sheet thickness, with snap head or countersunk head rivets respectively. If a smaller rivet than this is used, then more rivet rows will be required. It is common

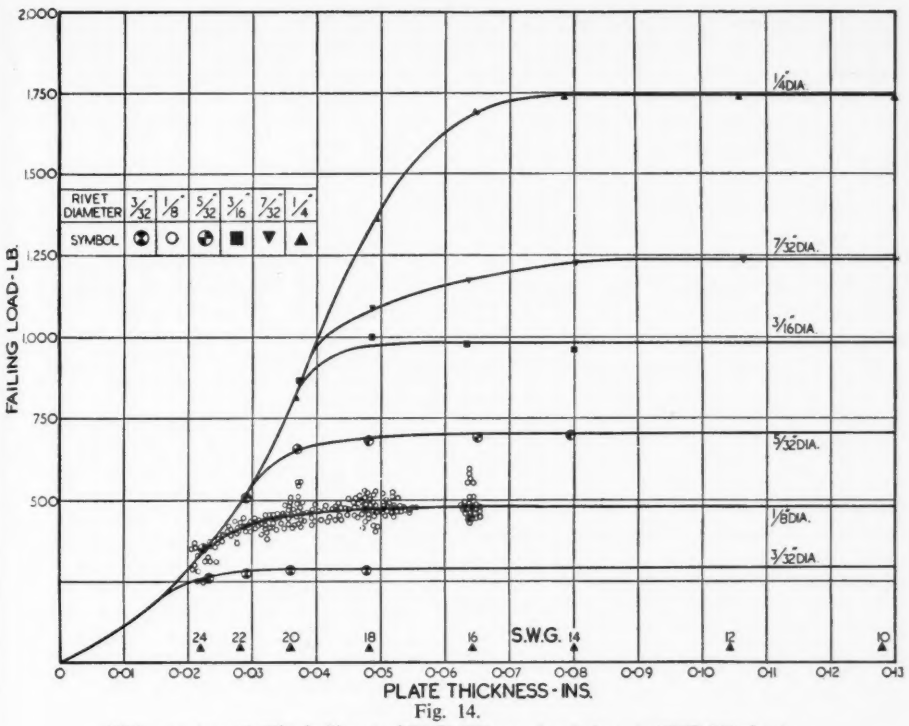


Fig. 14.

Ultimate strength (Single Shear) of DTD.327 snap head rivets in DTD.390 sheet.

practice with multi-row joints to allow a minimum distance of four rivet diameters between the rows, and to increase the rivet pitch in the end rows (conveniently by 100 per cent.), to improve the "tearing efficiency" of the skin at the final row of rivets.

Figure 12 shows a typical chordwise skin joint on the Brabazon wing designed for an end load of $P=7{,}750$ lb./in., with 120° countersunk head L.37 rivets cut countersunk in DTD.546 sheet. For multi-row butt joints, the butt strap is also made some 20 per cent. thicker than the skin for the same reason. Fig. 13 gives a general picture of the aluminium alloy riveting required to carry a given load (P) in a given sheet thickness. As the maximum size rivet that can be set cold at present is $\frac{1}{2}$ in. diameter, the number of rows increases beyond the three normally required to develop the maximum tensile strength of the sheet, to seven rows in $\frac{3}{8}$ in. thick sheet for a load of approximately 20,000 lb./in. The different regimes of bearing, tearing and rivet shear failures are also shown. It is also apparent that providing that the d/t ratio of 2.12 is not exceeded there is no penalty in using countersunk head rivets.

Another example worth considering is a joint in the high strength DTD.687 type aluminium sheet with an ultimate specification strength of 72,000 lb./in.^{2}.

To utilise the full strength of the material in tension an effective stress of some 64,500 lb./in.^{2} should be achieved. Unfortunately there is not an aluminium alloy rivet material at present available to give equivalent bearing strength of this sheet without artificially ageing after setting. L.37 rivets therefore are normally used.

It follows from (8) that at least three rows of snap head or six rows of countersunk head rivets will be required. In actual practice, due to the $\frac{1}{2}$ in. limit on rivet diameter, some nine rows of rivets would be required to develop the strength of $P=24{,}000$ lb./in. in $\frac{3}{8}$ in. thick sheet. It is in such cases that the limit of riveting is reached and a steel bolted joint is used. Another alternative is the use of "Hi Shear" pins.

It is commonly appreciated that the load distribution across a multi-row riveted joint is anything but uniform in the elastic regime, and it might be thought that because of this, there would be a drop in efficiency. In practice, at high loading conditions the rivets yield and the distribution in the plastic regime gradually approaches uniformity. Tests show that properly proportioned multi-row joints show little drop in efficiency.

This is in direct contrast to the glued joint where strength increases only slowly with increasing width of lap.

5.2. Strength test results

5.2.1. *Static proof and ultimate tests*

It is surprising that, when the Aircraft Industry was thirty years old, it was necessary to form a committee in 1942 with one of its terms of reference given as "The investigation of rivet strength." One of the reasons given was that aircraft firms were using design loads varying by two to one. Remembering the inordinate number of combinations of rivet and plate materials, diameters and thicknesses, it was understandable, but even so, it was not until December 1943 that there were standard data for such a common combination as an aluminium alloy L.37 rivet in a plate of DTD.390. These standardised loads are to be found in Chap. 401 of A.P. 970, and the work of establishing and publishing this data still goes on, in fact there is a great deal still to be done. Fig. 14 shows a set of results for snap head DTD.327 rivets in DTD.390 plates, as riveted by four different aircraft firms. Results plotted are mean test failing loads, with the individual points plotted for $\frac{1}{8}$ in. diameter only. Design values are some 10 per cent. lower for small rivet groups, but are increased to mean values for long uniformly loaded joints.

On the straight line portions of the curves the failure is simple shear, but above a D/t ratio of about three, the failure is partly by plate bearing. Effective shear stress diminishes as rivet size increases, probably because of proportional differences in actual diameter as riveted, and relative wire drawing effects.

The specified proof load these days is normally 2/3 of the ultimate load, and this has to be compared with the "proof strength" of the riveted joint. This poses the question, "What is the Proof Strength of a riveted joint"? This was originally chosen as that load producing a permanent distortion of two per cent. of the hole diameter, for steady loading, corresponding to a 4 per cent. slip of the joint. Subsequent performance of designs based on this has proved satisfactory, but it cannot be considered that the last word has been said on this. It is always open to changes dictated by further operational experience, or by new experiences with different types of riveting.

These proof design strengths were originally established by bearing tests on hardened pins in parallel holes, but this is particularly inapplicable for countersunk rivets, so they are now determined from direct tests on riveted joint test specimens.

Reference has been made so far to "steady load" conditions. Where vibration or load reversal conditions are present then the designer reduces the 4 per cent. slip values by a factor between 1.0 and 0.5, depending upon the severity of the loading conditions. Thus the Bristol factor for an engine mounting is 0.6.

Figure 15 shows the method of carrying out "Slip tests" at Bristol. Lap joints are assembled with two rivets in tandem, in tandem because few aircraft joints have the side-by-side single row arrangements, and also because rivet tilt and plate separation are somewhat reduced by this arrangement.

The edges of the joint are highly polished and a fine line is scribed across the centre line of the rivets. Cambridge travelling microscopes, with an accuracy of ± 0.0002 in. measure the separation of the two lines on

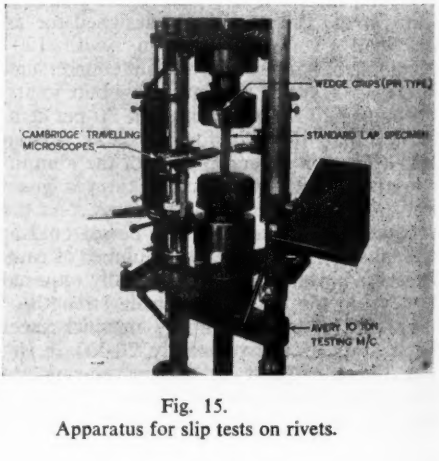


Fig. 15.
Apparatus for slip tests on rivets.

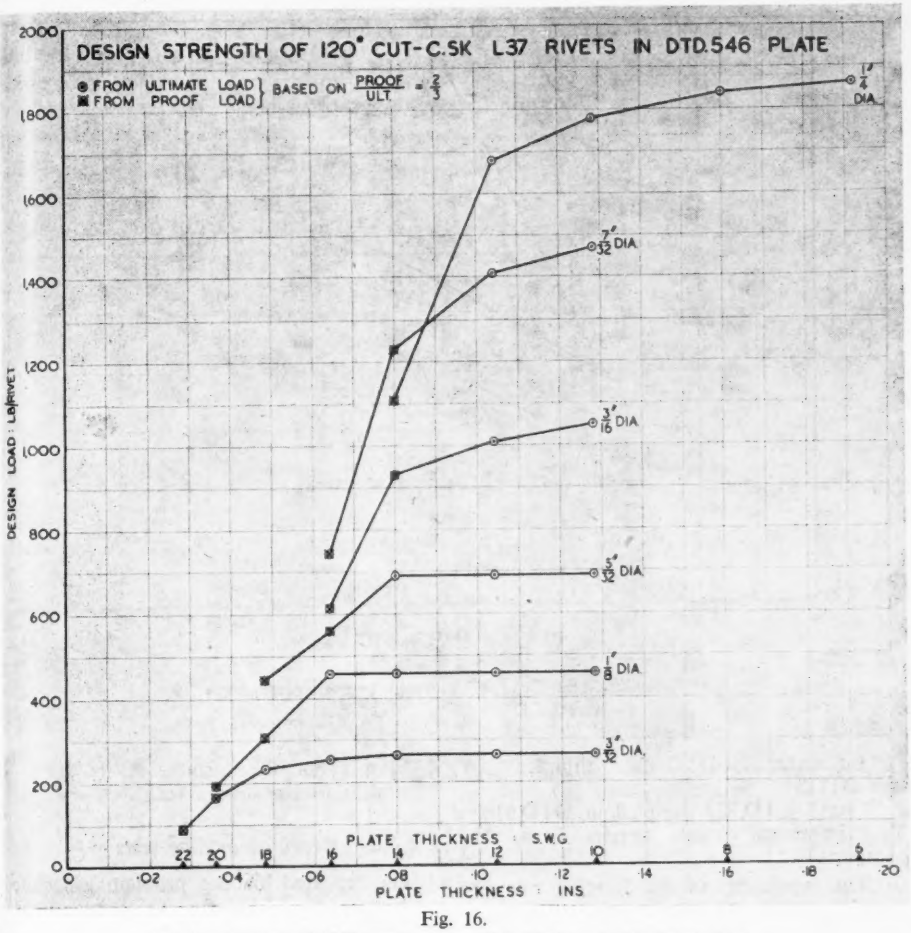


Fig. 16.
Design strength of 120° cut countersunk L.37 rivets in DTD.546 sheet.

the two pieces of sheet under load. A small "zero load" is applied and readings are taken, then the first increment is applied and readings are repeated, then the load is returned to zero for further readings, and similarly for all the succeeding increments.

By this method curves of load – total slip, and load – permanent set can be constructed and proof values determined from both curves. There is usually good agreement between the curves, but the load – permanent set curve is preferred rather than the total slip one.

Figure 16 shows the recommended design values for L.37 countersunk head rivets cut countersunk in DTD.546 sheet, based upon tests by Bristols according to the foregoing method.

The proof strengths are ratioed up by 3/2 to give a sort of "proof failure" figure, and the lower of this or the ultimate load is plotted. It will be noticed that, as pointed out before, providing that a D/t ratio of about 2.0 is not exceeded, then no reduction of shear strength to meet the proof requirement is needed.

Figure 17 shows a comparison of similar data for the following $\frac{1}{8}$ in. diameter rivets in aluminium alloy sheet:—

Solid L.37 cut countersunk in DTD.546
"Avdel" DTD.327 cut countersunk in DTD.610

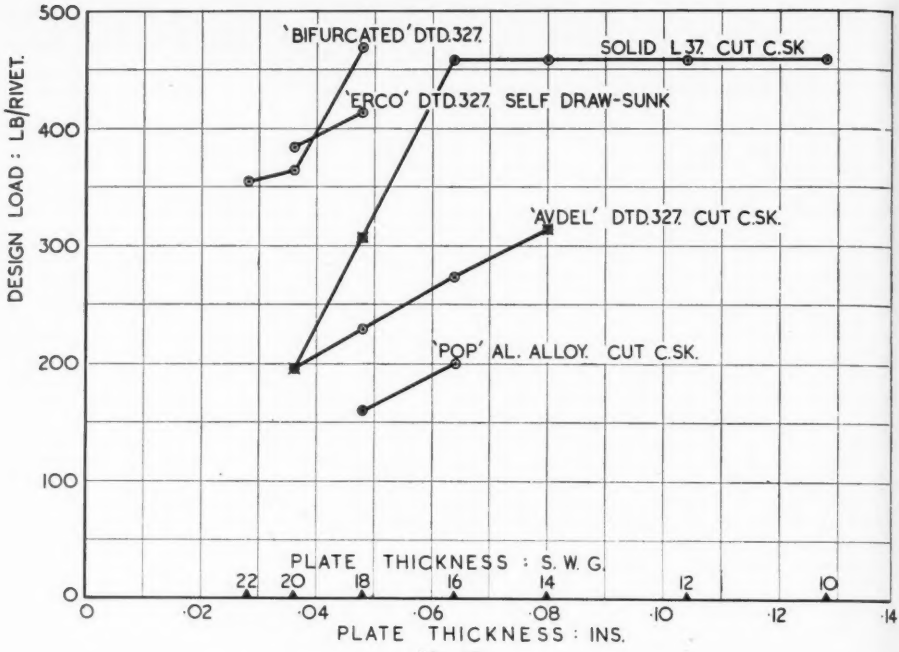


Fig. 17.

Design strength of 120° countersunk $\frac{1}{8}$ in. diameter rivets.

⊙ From ultimate load
× From proof load
} Based on Proof/ultimate = 2/3

"Bifurcated" DTD.327 dimpled in DTD.610

"Erco" DTD.327 dimpled in DTD.610.

Two important points appear from this comparison.

(*a*) The superiority of the dimpled countersink over the cut countersink, as exemplified by the "Bifurcated" and "Erco" processes.

(*b*) The superiority of the "Avdel" over the "Pop," but the former, in its turn, is inferior to the solid rivet.

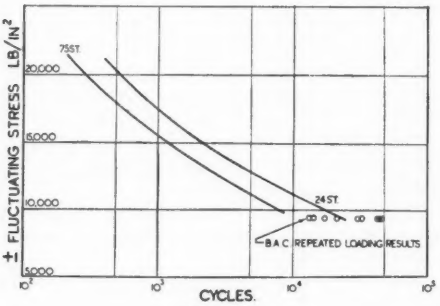


Fig. 18.

Boeing tests on repeated loading of riveted joints.

5.2.2. *Repeated loading tests*

The repeated loading problem associated with pressurised fuselages, which has already been described, has prompted the Company to give this aspect of rivet performance considerable attention. The Boeing Aicraft Co. of America has also studied this problem and Fig. 18 shows some of their test results. The curves show cycles to failure against half amplitude fluctuating stress, for 75 ST and 24 ST materials. Results achieved on the Bristol tests in DTD.546 single lap joints with L.37 rivets are also shown. It will be noticed that, on this evidence, the higher static strength 75 ST material is worse from the repeated loading aspect than the lower strength 24 ST alloy.

The former has a static ultimate tensile strength of approximately 63,000 lb./in.² in a properly designed riveted joint, but from the curves, a fluctuating stress of ±9,500 lb./in.² (*i.e.* a total amplitude of 19,000

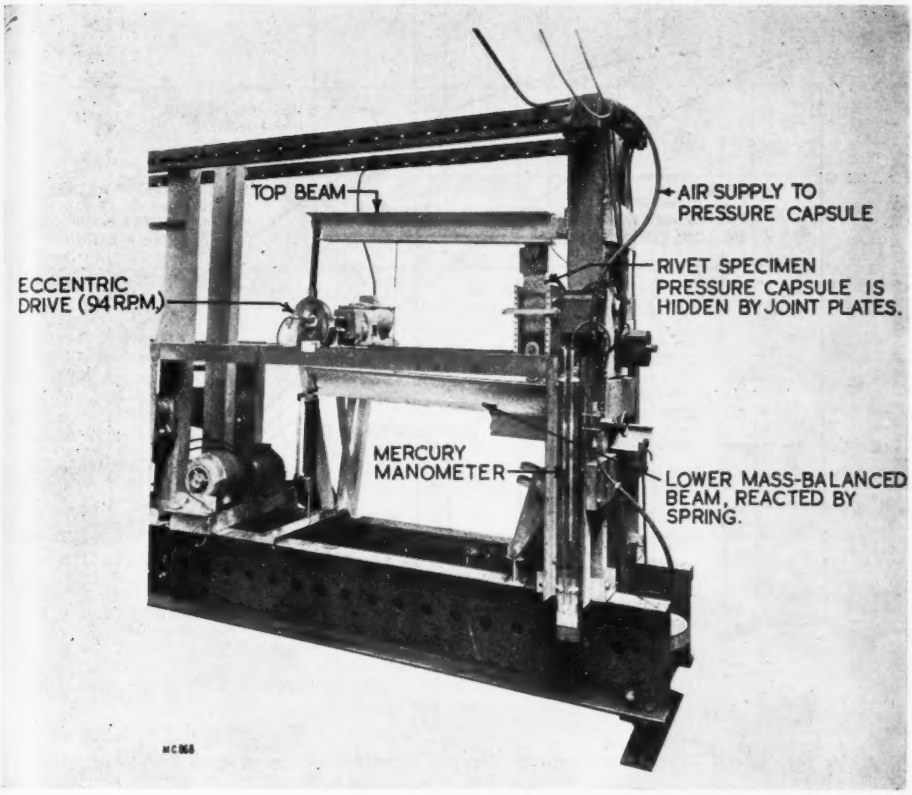

TOP BEAM
AIR SUPPLY TO PRESSURE CAPSULE
RIVET SPECIMEN PRESSURE CAPSULE IS HIDDEN BY JOINT PLATES.
ECCENTRIC DRIVE (94 R.P.M.)
MERCURY MANOMETER
LOWER MASS-BALANCED BEAM, REACTED BY SPRING.

Fig. 19.
Bristol Aeroplane Company repeated loading machine.

lb./in.^{2}) is seen to produce failure after 10^4 cycles. Thus an ultimate factor of $3\frac{1}{3}$ is required on pressurisation loads in order to achieve a satisfactory life in this material. The corresponding factor in DTD.546 alloy is $2\frac{3}{4}$. These factors compare with the minimum official static requirement of 2.0, which therefore is considered to be inadequate in these circumstances.

The Bristol Aeroplane Company has developed an electrically-driven mechanical loading rig for carrying out these tests on riveted joints, which is shown in Fig. 19. The specimen shown here is the Company's special capsule type for sealing checks, to which reference will be made later. The speed is 94 r.p.m. and a test to 10^4 cycles thus takes approximately 3 hours, including checks.

5.2.3. *Fatigue tests*

Fatigue strength is a full scale problem in its own right, so only the fringe of the subject can be considered in this lecture. Fig. 20 shows a number of test fatigue curves against the proposed fatigue requirements which have already been discussed. The top curve is the result of American tests on 17 ST polished bar material, and shows that this typical material has ample strength compared with the fatigue loads coming on to current aircraft structures. The stress concentration factor for a symmetrical double shear joint is about $2\frac{1}{2}$, and has been determined experimentally from photo-elastic tests. This enables the riveted joint curve to be deduced. The curve has also been checked experimentally for endurances of about 10^5 cycles.

Also shown are curves plotted from tests

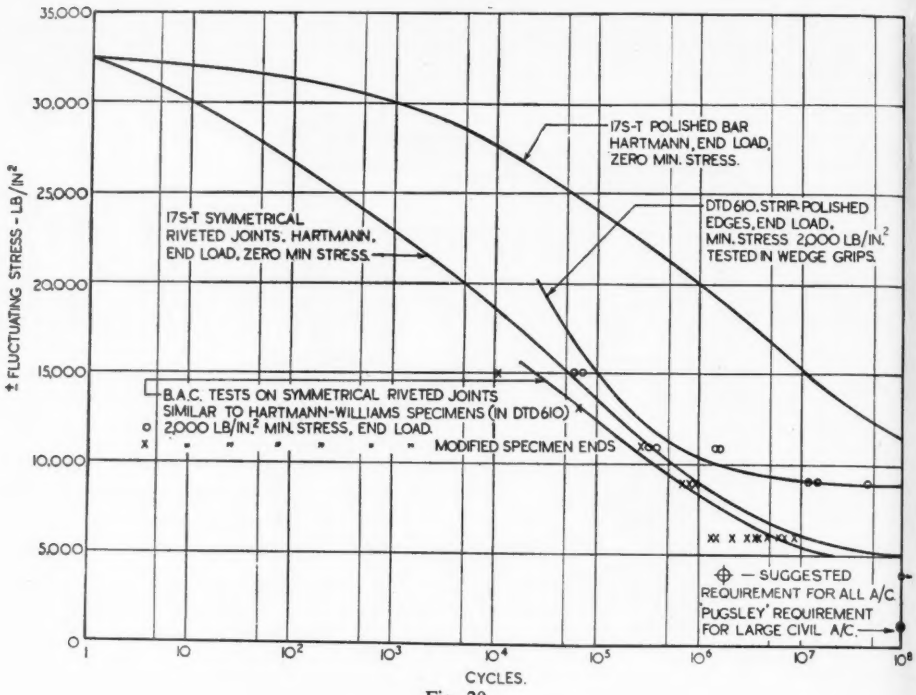


Fig. 20.
Basic fatigue test results.

made by the Bristol Aeroplane Company on plain DTD.610 sheet (roughly comparable to 17 ST) and for double shear riveted joints in the same material, for comparison with the American curve.

The riveted joint performance still beats the proposed requirements, although not by any very large amount, and any significant increase in operating level flight stress would be viewed with concern. A further cause for some reservation is the fact that the joints are of the double shear type not normally met on aircraft external surfaces. The asymetric single shear joint is much more common, has a higher stress concentration factor and presumably, a lower fatigue performance.

In all cases the failure is by fatigue of the sheet at the rivet holes and not failure of the rivets themselves.

6. MACRO-SECTION TESTING

In developing a new riveting process the macro-section technique is frequently used as a check on quality.

Samples of the riveted joint are carefully sectioned and mounted, polished and etched to bring out the grain flow, and then photographed with a magnification typically 10, but much larger if required.

The mechanical features of the joint (*e.g.* expansion of the rivet shank or tail) may be examined, and also the metallurgical grain structure may be checked for symptoms of cracking. The latter is particularly useful in processes such as rivet setting or spin dimpling, where violent cold work is being carried out on the materials.

Figure 21 shows examples of macro-sections of different types of rivets
A = close tolerance L.37 in hot dimpled sheet
B = Bifurcated rivet DTD.327 self simpled
C = Chobert with sealing pin
D = Chobert without sealing pin
E = Avdel
F = Pop

7. SEALING

Although rubber or plastic base compounds are superimposed on the riveted

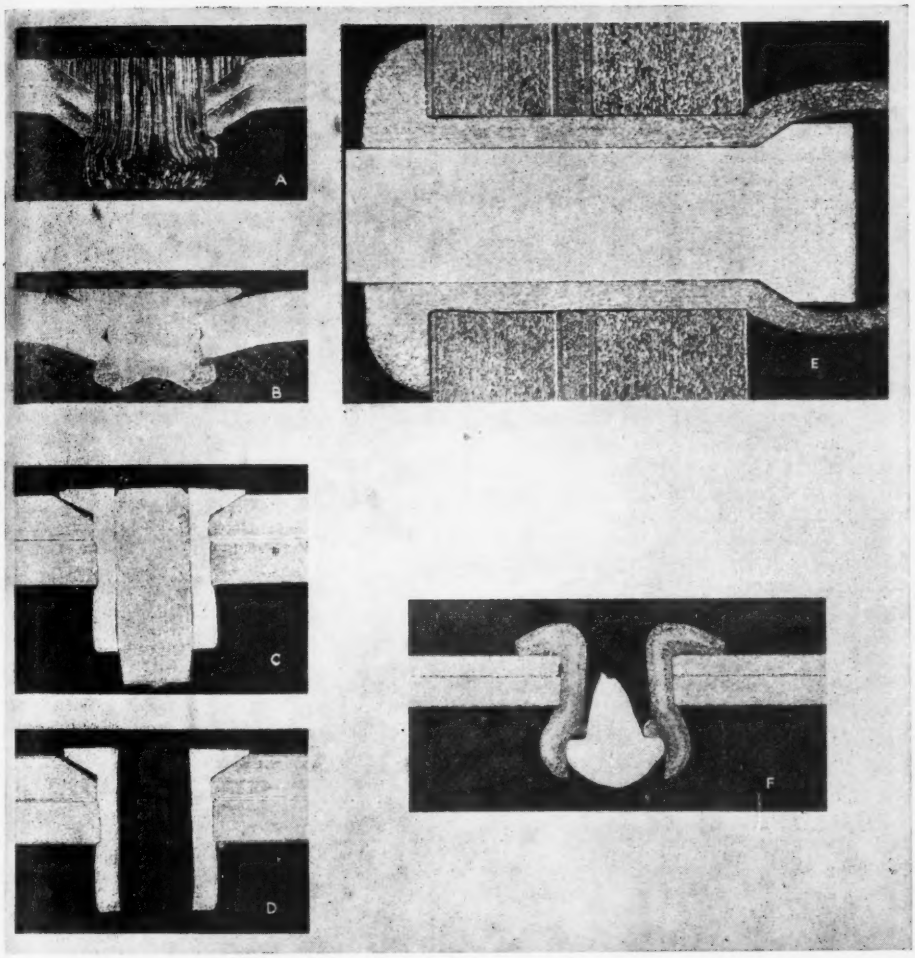


Fig. 21.
Macro-sections of various rivets.

joint where pressure or integral tank sealing is required, it is generally accepted that the maximum possible inherent sealing in the rivet joint itself should be achieved before this is done.

With the exception of the Consolidated Corporation of America, who use a neoprene strip between the mating faces of the joint, it is also generally accepted practice for the joint to be riveted dry and without any interface sealant. The superimposed sealant, for which a variety of satisfactory compounds are available, may be applied by brush, spray, puttying or filling processes, or by combinations of these methods.

For testing of the basic riveted joint the Bristol Aeroplane Company has developed a small capsule-type specimen, representing about 4 in. width of the joint. The rivets may be loaded to any desired extent at the same time as the joint is pressurised, and the leakage measured. The capsule is also immersed in a transparent tank full of water, and leakage under load may thus be observed visually. Two types of specimen are used, one which permits leakage, if any,

through the rivets only, and the other which allows interface leakage, as well as rivet leakage. The joints are arbitrarily pressurised to 12 lb./in.², and the rate of pressure loss is measured as the criterion of performance. The standard taken is that of a normal mushroom head rivet in the same sheet thicknesses, which is assumed to give the best performance. These tests are made,

(*a*) Under static loading at zeo, operating, and proof loads

(*b*) At various stages during the specified repeated loading tests

(*c*) At various stages during the specified fatigue tests.

The capsule type specimen is shown in the loading rigs of Figs. 15 and 22.

Typical results are shown in Fig. 23 for the static tests. These show pressure drop after 30 secs. and 5 mins., at zero, operating and proof loads, for two specimens of each type (Type A rivet leak only, and Type B total joint leak). These tests have established the following general facts:—

(*i*) No properly set solid rivet permits leakage through the rivet itself.

(*ii*) The "Bifurcated" semi-tubular rivet does allow some leakage through the rivet.

(*iii*) All joints tested permitted leakage between the faces of the sheets. This was much more pronounced with close tolerance dimpled countersunk riveting than with mushroom rivets.

(*iv*) There is no deterioration of sealing characteristics with repeated or fatigue loading. In fact in most cases the sealing improved, due presumably to the bedding down of the rivet and mating faces of the joint.

8. JOINT FINISH

Close tolerance rivets, hot and spin dimpling, controlled squeeze riveting, and rivet head milling, have all been described as aids towards improved joint finish.

The Chief Designer's thumb is a very inexact method of measuring surface waviness (although it is still the final arbiter of

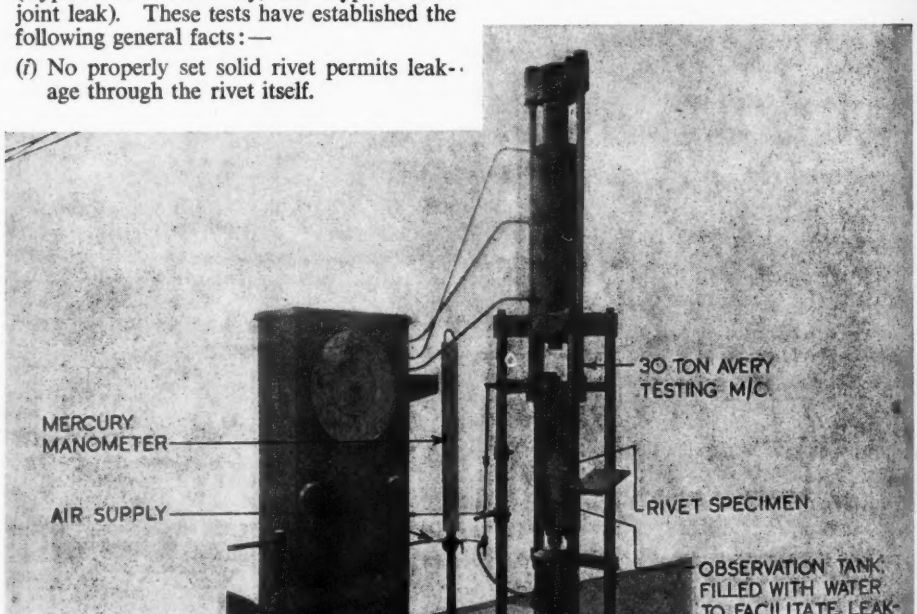
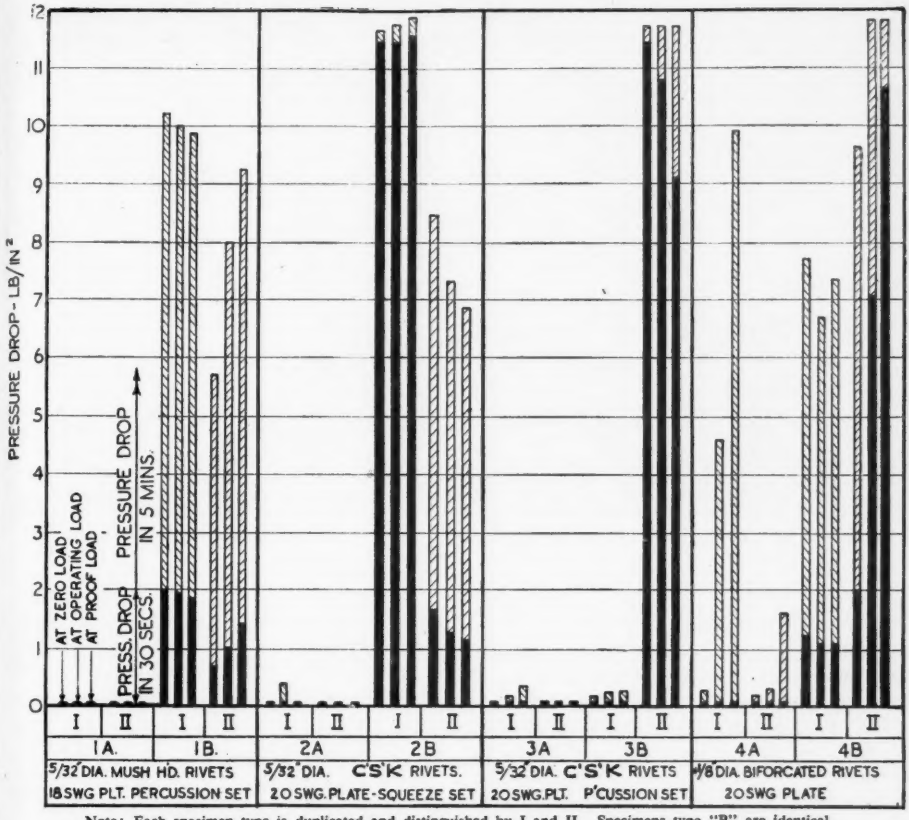


Fig. 22.
Apparatus for static sealing tests.


PRESSURE DROP - LB/IN²
AT ZERO LOAD
AT OPERATING LOAD
AT PROOF LOAD
PRESS. DROP IN 30 SECS.
PRESSURE DROP IN 5 MINS.
I II I II I II I II I II I II I II I II
1A. 1B. 2A 2B 3A 3B 4A 4B
5/32 DIA. MUSH HD. RIVETS 18 SWG PLT. PERCUSSION SET
5/32 DIA. C'S'K RIVETS. 20 SWG. PLATE-SQUEEZE SET
5/32 DIA. C'S'K RIVETS 20 SWG. PLT. P'CUSSION SET
1/8 DIA. BIFORCATED RIVETS 20 SWG PLATE

Note: Each specimen type is duplicated and distinguished by I and II. Specimens type "B" are identical with type "A" except for the addition of a 1/16 in. dia. in rear skin to permit inter-face access.

Fig. 23.
Static sealing tests on lap riveted joints.

choice), and the Company has developed an electronic method for reproducing the actual surface finish to any required degree of magnification. This apparatus, popularly known as "the Electronic mouse," is shown in Fig. 24. It consists of a driven inductive head which traverses the surface to be examined, calibrated to give a known response to a known deflection. The impulse due to the deflection is fed to an amplifier and a cathode-ray oscilloscope, which is photographed by a constant speed film camera. Using this apparatus all the significant factors can be assessed that contribute towards a flush finish—or otherwise; among these are rivet tilt, head flatness, inter-rivet skin distortion, burring and so on. Trends can be established which would be well-nigh impossible to determine if no intimate trace were available. It is a very powerful weapon to have available when trying to give an objective judgment on the merits of this, that, and the other process submitted by the development or production departments.

Typical results are shown on Fig. 25, and the particular comparison shown gives great emphasis to the virtues of a thick skin!

The conventional surface finish requirement from aerodynamic considerations is ± one thousandth per inch. This standard can be achieved with carefully placed close tolerance solid riveting in thick sheet (16 SWG and upward), but in thin sheet it is only approached by close tolerance "Avdel" riveting with the heads milled flush in spin dimpled holes.

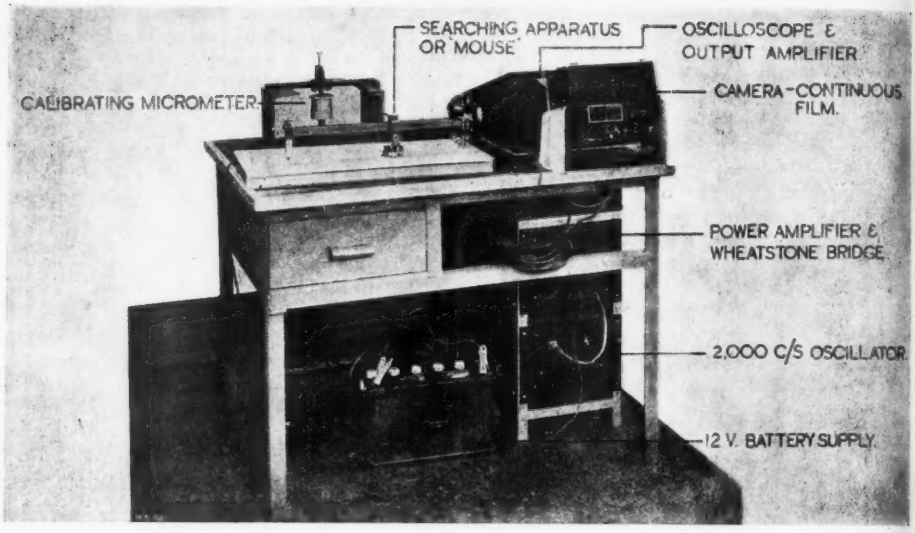


Fig. 24.
Apparatus for skin smoothness measurement.

9. RIVET WEIGHTS

A few approximate figures about aluminium alloy rivets in the Brabazon may be of interest.

There are approximately two million rivets in the aircraft, the largest being $\frac{3}{8}$ in. diameter. All external surfaces are flush riveted with the exception of the fuselage, the gross surface area being approximately 22,000 ft.^{2}.

In this instance only the weight of the heads and tails are considered, and typical weights of these are as follows:—

$\frac{1}{4}$ in. diameter countersunk head
0.0016 lb. per rivet

$\frac{1}{4}$ in. diameter mushroom head
0.0029 lb. per rivet.

There is thus an appreciable weight saving by using the countersunk rivet. The total weight of rivet heads and tails on the Brabazon is approximately one ton and if the fuselage were flush riveted by cut countersunk methods, the saving would be approximately 250 lb.

Control of the protrusion length, previously mentioned, yielded an estimated saving of 200 lb. in weight.

It is obvious that on a large aircraft such as this, the penalty of using steel rivets or bolts would be considerable. From strength considerations it might be considered on the inner wing main box structure, but the weight penalty would probably be in the region of 1,000 lb., possibly more.

10. RIVETING COSTS AND SPEEDS

The following figures of the first cost of the rivets give some comparison between the different types. They all relate to $\frac{1}{4}$ in. diameter aluminium alloy rivets with countersunk heads, $\frac{1}{4}$ in. long, and are costs per 1,000 rivets.

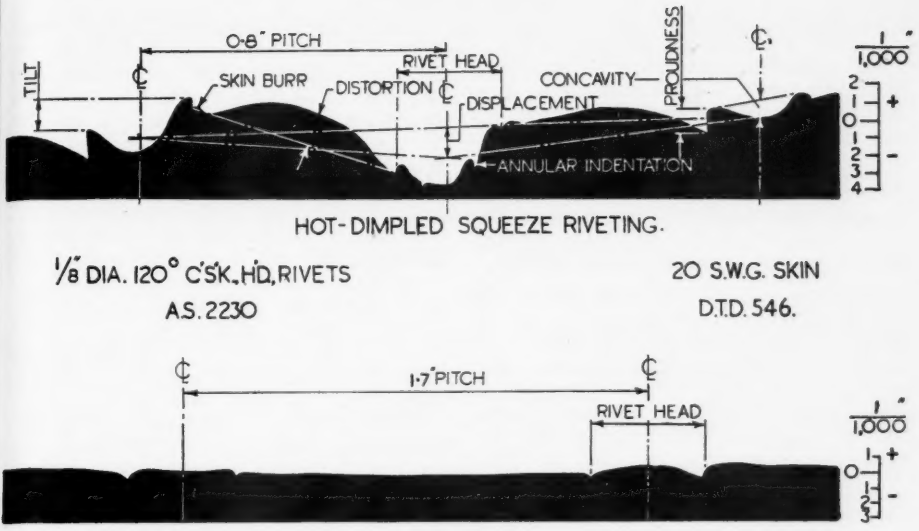
Rivet type	*Cost per* 1,000 £	s.	d.
Solid forged rivet AS.2230/404		5	0
Solid machined rivet AS.2919/404	1	6	9
"Pop" rivets TAP/K/BS.423		13	9
"Chobert" rivet T.K.4C NA (with sealing pin)	2	5	0
"Avdel" rivet 372/404.5	7	13	0
"Cherry" self-plugging type	7	10	0

Three things are apparent:—

(*a*) The increased cost of the close tolerance machined rivet compared with the normal forged type.

(*b*) The economy of the "Pop" rivet.

(*c*) The high cost of the "Avdel" and "Cherry" rivets.



HOT-DIMPLED SQUEEZE RIVETING.

1/8" DIA. 120° C'SK. HD. RIVETS
A.S. 2230

20 S.W.G. SKIN
D.T.D. 546.

CUT-C'SK., REACTION RIVETING.

5/16" DIA. 120° CSK. HD. RIVETS
A.S. 164.

7 S.W.G. SKIN
D.T.D. 746.

Fig. 25.
Characteristics of riveting profiles.

Approximate rivet costs for three Bristol aircraft are given below. The Type 170 has normal tolerance riveting while the other two have all skins riveted with close tolerance rivets.

Bristol Aircraft Type	*Approximate cost of rivets* £
170 Freighter-Wayfarer	200
175 (M.R.E.)	3,000
167 Brabazon	7,000

It will be seen that these costs are small in relation to the total cost of the airframe.

Type of rivet and method of setting	*Speed rivets per min.*
Overall hand setting of solid rivets	10-20
Fixed squeeze riveters	6
"Bifurcated" process including dimpling	25
"Erco" process including punching of holes and dimpling	15
"Pop" riveting	20
"Chobert" (with sealing pin)	10
" (without sealing pin)	18
"Avdel" riveting (snap head)	4
" countersunk, including milling	2

Typical speeds for sheet preparation are also as follows:—

Drilling of holes	6
Spin dimpling	15-20

In attempting to assess the riveting speeds it is realised that they vary enormously between different firms and types of job, but the figures quoted are the result of an honest attempt to arrive at an overall average estimate.

It will be seen that overall speeds for the complete process vary between the fastest of 15 a minute for the "Erco" process, 3 a minute for the separately drilled, spin dimpled and squeeze set solid rivet, and 1½ a minute for the separately drilled, spin dimpled and milled "Avdel." Plain hand-setting of solid rivets in drilled holes gives an overall speed of about 3-5 a minute.

The great advantage in speed achieved with the "Erco" process is due to the ability to punch the hole in the one sequence of setting operations, without prior sheet preparation.

11. CONCLUSIONS

The author believes that riveting, in the immediate future, will still form the principal method of fabricating aircraft structures, but that its field of use will get smaller.

There is a need for an aluminium alloy rivet material with an ultimate tensile strength of at least 30 T/in.^{2}, but which may be set satisfactorily with no worse complications than those given by natural ageing.

Even given this material, new projects will require such large rivets or, alternatively, so many rows of rivets, that in some cases designers will resort to other methods. These other methods may be either the use of H.T.S. bolted joints, or the elimination of the heavily loaded joints completely by machining surfaces from the solid.

Another influence leading to less use of riveted joints is the development and increasing use of metal adhesives. The development of moulded plastic, and machine-welded magnesium structures is also well under way and will further restrict the field.

At the present time the emphasis is on riveting finish, and to a lesser extent on pressure sealing. The development of improved finish is being achieved irrespective of greatly increased cost, but it is felt that the cost and time aspects will eventually force a compromise, and the fully automatic flush riveting processes such as the "Bifurcated" and "Erco" types, will be used.

Finish apart, the trend is at present towards more machine set riveting, which requires considerable subdivision of structure, and increased jigging.

In the "Blind" riveting field a rivet fully equal to the American "Cherry" is still lacking in Great Britain and further development of the "Avdel" rivet is required.

Existing standardised rivet strength data still leaves much to be desired, and much more static testing is necessary to provide this.

The author thanks the Bristol Aeroplane Co. Ltd. for permission to give this lecture, and also those of his colleagues who assisted him by providing various data which he has used.

SUMMARY OF THE ACTIVITIES OF THE SOCIETY

JANUARY—DECEMBER 1950

THE following places on permanent record in the JOURNAL the Notices which have appeared in the Monthly Notices and so summarises the activities of the Society for the year. Activities not reported in the Summary will be given in the Annual Report of the Council which will be published in the July 1951 JOURNAL.

ANNUAL GENERAL MEETING

The Annual General Meeting was held on Monday, 15th May 1950, in the offices of the Society.

PRESENT

Sir John Buchanan, President, in the Chair for the first part of the meeting,
Major G. P. Bulman, President-elect, for the latter part of the meeting.

Mr. W. J. D. Annand, *Assoc. Fellow*
Mr. S. B. Bailey, *Assoc. Fellow*
Mr. J. Bell, *Associate*
Mr. C. W. E. Browse, *Fellow*
Mr. A. V. Cleaver, *Associate*
Dr. H. Roxbee Cox, *Fellow*
Mr. Handel Davies, *Fellow*
Dr. G. P. Douglas, *Fellow*
Mr. A. H. Fear, *Assoc. Fellow*
Mr. A. H. C. Greenwood, *Associate*
Mr. N. J. Hancock, *Assoc. Fellow*
Mr. J. W. F. Housego, *Graduate*
Mr. G. Ingram, *Associate*
Mr. H. A. Jarrett, *Assoc. Fellow*
Mr. R. S. Khot, *Assoc. Fellow*
Mr. Peter Masefield, *Fellow*
Mr. L. Mawer, *Assoc. Fellow*
Mr. N. S. Muir, *Fellow*
Mrs. W. Neal, *Assoc. Fellow*
Mr. D. R. Newman, *Assoc. Fellow*
Mr. E. Pribram, *Assoc. Fellow*
Mr. W. P. Savage, *Fellow*
Mr. D. C. Smith, *Assoc. Fellow*
Mr. C. F. Uwins, *Fellow*
Mr. J. H. W. Wheatley, *Assoc. Fellow*
Mr. R. H. Whitby, *Assoc. Fellow*
Mr. L. A. Wingfield, *Assoc.*
Mr. C. G. Woodford, *Assoc. Fellow*
Mr. A. H. Yates, *Assoc. Fellow*

In attendance: The Secretary and Miss Barwood

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1. The Secretary read the Notice convening the Meeting.
2. The Report of the Council on the state of the Society and the Balance Sheets of Aerial Science Limited and Aeronautical Trusts Limited for the year ended 31st December 1949 were presented. The President drew attention to some of the outstanding items in the report, including the founding of the Charter Scholarship; the Anglo-American Aeronautical Conference in New York in May 1949; publication of "The Aeronautical Quarterly"; and the launching of a new type of lecture called Specialist Lectures.

   Mr. Handel Davies, *Fellow*, said that the data sheets could not have been produced without the very fine work of the technical staff and he would like to see the staff's work acknowledged in the published report.
3. As a result of the ballot the Secretary reported the following nominations to fill the vacancies on the Council:

   Mr. S. Camm
   Mr. W. S. Farren
   Professor A. A. Hall
   Mr. N. J. Hancock
   Mr. E. T. Jones
   Mr. P. Masefield
   Mr. S. Scott Hall

4. The Secretary read the names of those proposed for *Fellowship* and passed by the Council as follows:

J. L. P. Brodie, M.I.A.E., M.I.Mech.E.
Air Vice-Marshal R. O. Jones, C.B., A.F.C.
E. J. Richards, M.A.
P. L. Teed
F. W. Whitehead
C. T. Wilkins

5. It was agreed that Messrs. Price Waterhouse be re-appointed Auditors for the ensuing year for Aerial Science Limited and Aeronautical Trusts Limited.

6. Under Any Other Business, Sir John Buchanan said he would like to express his deep appreciation of the help he had received during his term of office from the staff. He would like to say how much he regretted Captain Pritchard's retirement from the Society and expressed the hope that the Society could call on him for help and advice in the future.

The Garden Party was a great success and was entirely due to the efforts of the permanent staff of the Society and he would like this fact placed on record.

7. Sir John Buchanan said it was now his pleasure to introduce Major G. P. Bulman as the new President of the Society. He knew members would give him all the support and encouragement he himself had received during his term of office.

Major Bulman, in reply, said he hoped to maintain at all times in all places the dignity of the Society. He would bear in mind particularly the young members of the Society.

8. Dr. Roxbee Cox, proposing a vote of thanks to the out-going President, said it had not been a particularly easy year but Sir John Buchanan had guided the Council in a consummate way.

In saying farewell to him he felt all would do so in the knowledge that they could continue to have his help and guidance.

The meeting then closed.

HONOURS

The following members of the Society received awards in 1950:—

NEW YEAR HONOURS—JANUARY 1950

K.B.E.

Air Vice-Marshal A. de T. Nevill, *Assoc. Fellow.* (President, New Zealand Division of the Royal Aeronautical Society.)

C.B.

S. Scott Hall, *Fellow.*
Air Commodore J. F. Titmas, *Assoc. Fellow.*

C.B.E.

F. M. Owner, *Fellow.*
K. T. Spencer, *Fellow.*

O.B.E.

R. M. Clarkson, *Fellow.*
W. Courtenay, *Associate.*
G. B. S. Errington, *Assoc. Fellow.*

M.B.E.

J. Norman, *Assoc. Fellow.*

KING'S COMMENDATION FOR VALUABLE SERVICES IN THE AIR

Air Vice-Marshal D. C. T. Bennett, *Fellow.*

BIRTHDAY HONOURS

BARON

E. W. Hives, *Fellow*.

K.C.G.B.

Air Chief Marshal Sir Ralph Cochrane, *Assoc. Fellow*.

K.C.B.

Sir Ben Lockspeiser, *Fellow*.

C.B.E.

F. T. Hearle, *Fellow*.
Captain J. Laurence Pritchard, *Hon. Fellow*.
T. Rowntree, *Fellow*.

O.B.E.

H. P. Folland, *Fellow*.

INSTITUTE OF THE AERONAUTICAL SCIENCES

The Council of the Institute announced the following elections of members of the Society in 1950:—

To *Fellowship*:

Dr. J. J. Green, F.R.Ae.S.
A. E. Russell, F.R.Ae.S.
Bo K. Lundberg, A.F.R.Ae.S.

GUGGENHEIM MEDAL

The Guggenheim Medal (U.S.A.) for 1950 was awarded to Dr. E. P. Warner, *Hon. Fellow*. The medal is awarded for pioneering in research and a continuous record of contributions to the art and science of Aeronautics.

THE ROYAL SOCIETY

The following members of the Society were made Fellows of the Royal Society in 1950:—

R. A. Fraser, B.A., D.Sc., *Fellow*
S. B. Gates, O.B.E., *Fellow*
L. Howarth, B.Sc., M.A., Ph.D., *Assoc. Fellow*

The Rumford Medal of the Royal Society was awarded to Air Commodore Sir Frank Whittle, K.B.E., C.B., C.B.E., D.Sc., F.R.S., F.R.Ae.S.

THIRD ANGLO-AMERICAN AERONAUTICAL CONFERENCE—1951

Arrangements were begun in September 1950 for the Third Anglo-American Aeronautical Conference, convened jointly by the Royal Aeronautical Society and the Institute of the Aeronautical Sciences (of America), which will be held at Brighton, Sussex, during September 1951.

Previous Conferences were held in London in 1947 and in New York in 1949.

ELECTION OF PRESIDENT AND VICE-PRESIDENTS

Major G. P. Bulman, C.B.E., B.Sc., *Fellow*, was elected President of the Society for 1950-51 and took office at the Annual General Meeting on 15th May 1950.

The following were elected Vice-Presidents of the Society for 1950-51 at the Meeting of Council held on 24th May 1950:—

S. Camm, Esq., C.B.E., *Fellow*
G. R. Edwards, Esq., M.B.E., B.Sc., *Fellow*
Major F. B. Halford, C.B.E., *Fellow*

THE SECRETARY

The approaching retirement of Captain J. L. Pritchard, C.B.E., *Hon. Fellow*, Hon. Fellow I.Ae.S., Secretary of the Society since 1925 and Editor of the JOURNAL

from 1919-1946, was announced by the Council in May 1950. A Testimonial to the Secretary for presentation to him on his retirement in recognition of the high esteem in which he is held was announced shortly afterwards. An appreciation of Captain Pritchard and his work for the Society, together with the letter which was issued and signed by the President and Past-Presidents on the Council in connection with the Testimonial Fund, was published in the May 1950 JOURNAL.

ELECTIONS OF NEW MEMBERS AND TRANSFERS OF MEMBERSHIP

JANUARY 1950

Associate Fellows

Arthur James Almond, Henri Amiot, Eric Nigel Atkey (from Graduate), Thomas Webster Bagshaw (from Graduate), William Anthony Cann, John Frederick Cannell (from Graduate), Eric Neville Crabbe (from Student), Joseph Crane, Maurice Cecil Curties (from Graduate), Austin Roy Fox (from Graduate), William Gillespie, Robert John Griggs (from Graduate), Thomas Allan Harvie (from Graduate), Ernest Hobart (from Student), Leslie Howarth, Norman Parry Hughes (from Associate), Louis Kahn, John William Langworthy (from Graduate), Thomas Dane Martin, Norman Alfred Miller, Leslie Sydney Dennis Morley (from Student), Douglas Edward Pay, Arthur Charles Samuel Pindar, Hilary John Silvanus Pinsent (from Student), Gordon Albert Pullinger (from Student), Desmond Leonard Rendell (from Associate), Evers Turner Buchanan Smith (from Graduate), Wilfred Smith, Raymond Spencer Soloman, Douglas Oliver Spratt (from Associate), Donald Lee Taylor (from Associate), Maurice Vernon Taylor, John Richard Thirkettle (from Graduate), Bryan Thwaites, Ernest Toner, Cameron Arthur Turner, Philip Edward Tweed, Allen Chivers Walker, Hubert Beresford Walker (from Graduate), Francis John Powell Wood, William Glanville Woodward (from Associate), John Wotton.

Associates

Ian Darling Anderson, Eldred Ashton (from Student), Charles Herbert Baldwin, Arthur Edwin Briggs, Alan Howard Brooks, Thomas Malcolm Grahame Bury, David Albert Ronald Carter, Wilfred Ernest Casley, Thomas Edward Davis, Edmund Frank John Gericke (from Companion), Stuart George Hall, Harry Heap, Ronald Frederick Hill, Arthur Frederick Hindell, Alan Alfred Hughes, Walter James Arthur Humphries, Albert Victor Parker, Kenneth Arthur Steel, Jean Taton, Guy West Underwood, Geoffrey Leonard Freeman Welham.

Graduates

Eric Bertram Alexander, Phillip Hayden Baldwin, Stanley Michael Baldwin, Peter John Bell (from Student), Ronald Vincent Belvoir (from Student), Alec Tom Binding, Robert Alexander Ross Black, Brian John Bleaney, Thomas Brindley Booth (from Student), Peter Bradshaw (from Student), Peter Brett (from Student), Reginald Arthur Bridgeman (from Student), Alan James Bullock, Christopher Edwin Burrows (from Student), Alan Henry Butler, John Burton Harris Campbell, Alfred George Campion, Edward Christopher Carter (from Student), Anthony Lambert Cole (from Student), John Robert Collingbourne, John Stuart Collins, Douglas Colin Cox, John Perran Curry (from Student), Richard John Davies, Clifford Henry Davis (from Student), Frederick Walter Dee, Ralph Murch Denning (from Student), William Ernest Digweed (from Student), Donald Stephen Dugdale (from Student), Ronald George Edwards, Robert Charles Eeles, John Derek Ellis, Albert David Fowler, George Edward Fowler, John William Fozard, Peter Lawrence Edward Gallimore (from Student), Donald Ganson, Nilansu Ghose, Richard Wilfred Goddard, Alan John Goodwin, Ronald Grey, Dennis Victor Hadnutt, George Thomas Hayes, Alan George Hobbs (from Student), Maurice Donald Hodges (from Student), Rex Richard Howlett (from Student), Desmond James (from Student), Donald Joseph, John Robert Denis Kenward (from Student),

Edward Geoffrey Lewis (from Student), Ernest Arthur Lewis, Gordon Walter Little, Robert Angus Mackay, Charles Algernon Mathias, Charles William May, Spencer Davidson Meston (from Student), Thomas John Methven, Jeffrey Nicholas Montgomery (from Student), Brian Ronald Morris (from Student), Arthur Owen, Terence Clive Owens, John Henry Paterson, Brian William Plenderleith (from Student), Janusz Stanislaw Przemieniecki, John Leonard Raynes (from Student), Ronald Albert James Regan; Brian Reynolds, Gerald Edward Harry Rice, Anthony Max Richards, Roger Gordon Richards (from Student), Arnold Rose, William Colin Ruler, James Beat Scott, Geoffrey Gordon Semark (from Student), Bryan Charles Smith (from Student), Neil Hickman Stewart, David Thomas John Stops (from Student), James Donald Storer, John Hunter Taylor, Desmond Arthur Treadgold (from Student), Donald William Trebley, Geoffrey Michael Trewinnard (from Student), James Gillette Try (from Student), Michael Henry Lewin Waters (from Student), Denis Edward Williams, Geoffrey Edward Williams (from Student), Robert Hugh Williams (from Student), William Gerald Williams, Paul Heinz Walter Wolff (from Student).

Students

Michael John Gerry Ash, Roger Frederick Back; Arthur Sidwell Bennett; Dennis Bernard Black, Gobinda Chandra Chatterjee, Deryck Walter Childs, George Allan Collins, Douglas Henry Cook, Trevor Storr Davies, Barry Vincent Davis, Geoffrey Michael Deacon, Kenneth Deegan, Dakshina Ranjan Dutt, Friedericke Englander, Hamid Farooq, Montague Samuel Edmund Gumbley, Jeffery Philip Hawkins, Ian Douglas Huntley, Matthew Alexander Hutchison, David John Leahy, Brian Alexander MacDowel, Ronald Conway Margetts, Hugh Somerton Mettam, Raymond John Miskin, Leslie Frank Nicholls, John Jacob Rudolf, Geoffrey Arthur Clayden Searle, Norman Woodhead Seccombe, David Shellard, John Hyslop Steele, Brian Rodney Townsend, Neville Upton.

Companions

Lawrence Kershaw Lord (from Student), Ralph Thomas Sage, C. R. Rajagpal.

FEBRUARY 1950

Associate Fellows

Ernest Henry Alford, Robert Allan, Ian Kenneth Bennett (from Student), Arthur Harry Oliver Brown, Frank Frederick John Butler, Denison Campbell-Allen, Leslie Ellerd-Styles, Necdet Eraslan, Jeffrey Hammerton Harwood (from Student), Dennis Hill, Leon Massie, William Henry Mayall (from Graduate), Raymond Frederick Sargent (from Associate), Gordon Morrison Silvester (from Graduate), Harold James Staite, John Wallace Titterton.

Associates

Douglas Raymond Bevis, Gordon Davies, Derek Eccles, Thomas Hewitt, Charles Henry Johns, Archibald Cranleigh Stagg.

Graduates

Norbert Abeles, Peter Joseph Angus, Kenneth Bickerstaff, Michael Booth (from Student), James Robert Campbell, (1) Peter Walker Campbell, (2) Peter Walker Campbell, Roy Edward Champken, John Maurice Chard, Eric Alan Coates (from Student), Alan Frederick Boniface Constantine (from Student), Peter Herbert Cook (from Student), Anthony David Cowell (from Student), Peter John Cunningham, Alan Robert Daffey, Jack Sidney Dean (from Student), Clifford Ditchfield, Arthur David Ellis, Stanley Hargreaves Ellis (from Student), William Little Farish, Robert Charles Godwin (from Student), Alan James Greenhalgh, Stuart William Greenwood (from Student), John Harold Grout, Peter John Hext Hall, John Dennis Hallett, Vernon Alexander Hallett, John Hawthornthwaite, Donald William Hayward, James Rentoul Henry (from Student), Rodney Graham

Hinkley (from Student), John Ernest Hommert (from Student), Michael Stanley Stather Hunt, Derek Anthony Jackson, Arthur Albert Jacobs (from Student), John Einion Glyn Jones, Derrick Pritchard Jones, George Charles Brian Harvey Kenrick (from Student), John Nevil Kirkby, David Leek, Philip Reginald Lewis, Romney Hollins Lowry, Ian Stuart Mant, Alexander Leslie Mayne, Francis John Morley, Roger Hetherington Peart, Bertram Anthony Peaster, James Stanford Plowman (from Student), Brian Ben Priestley, David Ronald Arthur Puttock, John Patrick Charles Richards, Terence Compton Stamp, Xavier Hubert Joseph Strick, Peter Anthony Tanner, Peter George Taylor, Peter Drake Thompson, Stephen William Tonkin (from Student), Robert Longley Trillo (from Student), Alexander Uydens (from Student), Peter Redmore Ward, Peter Ernest Watts (from Student), Rex Wheatley, Peter Charles Harford White (from Student), George Wilson, Mieczyslaw Longin Wisniewski, Wilfred Joseph Woods (from Companion).

Students

Ronald Edward Bellew, Dennis Ryan Brodie, William Tudor Gunston, Lars Eric Haggstrom, Thomas Henry Jones, Lois Jennifer Lee, Basil Thomas Lewis, Victor Stephen Lodge, Philip Arthur Norman, Rees Oakes, David William Rowe, Edmundo Gomes Ferreira daSilva, Gordon Sim, Paul Simpson, Anthony Compton Southgate, Christopher Staffurth, Michael Jordan Taylor.

Companions

Saul Jecies, Norman Leslie Edwin King (from Student), Ved Kumar, Eldon Malcolm Phillips, Kulbir Singh (from Student).

MARCH 1950

Associate Fellows

Ian Hammond Blick (from Graduate), Frederick Brian Butler (from Graduate), Edward James Buxton, Alan Edmund Clarke (from Graduate), Victor William George Curtis, Thomas Geoffrey Daish (from Companion), John Francis Dooley (from Graduate), David Hallowell Earle (from Student), Alexander Greer, Reginald Ronald Hanson, Arthur Marchall Harris, Cecil Henry Jones (from Graduate), Robert John Jupe (from Graduate), Leonard Ferguson Kenna (from Graduate), William Henry Morgan, William Joseph Francis Moschini, John Shirley Naylor (from Student), David Lawrie Raffle, John Eric Rhodes (from Graduate), John Kenneth Robinson (from Student), Robert Trevor Shields, John Raymond Stevens (from Graduate), Icko Szloma Tenenbaum, John Graham Walker (from Graduate), Raymond Archibald Watts (from Graduate), Robert Charles Webb, Douglas Charles Williams.

Associates

John Bamford, Kenneth Victor Bonney, Eric Latham Beverley, Francis Holley Burnett, Geoffrey John Wraighte Clark, William Essex Devonald, Cornelius Durham Garbutt, Albert Henry Jane, Joseph Wilton Johnson, David Charles Lambert Lovell (from Student), Russell Paul Manning, Patrick Kavanagh Relton, John Alexander Gwynne Tucker, Clifford Reed Wills.

Graduates

David William Allen, Royston Jeffries Allen, Robert Henry Watson Annenberg (from Student), Austin Barltrop (from Student), Greville Gordon Beale, Edgar Bendor, Sidney Thomas Blakemore, Anthony Robert Southby Bramwell, Earl Francis William Brown (from Student), Jack Toynbee Burr, John Byrne, Geoffrey Samuel Canetti, Ruthven Lamble Carstairs, Eric John Catchpole (from Student), William Alfred Caws (from Student), John Anthony Dunsby (from Student), George Emerick, Cyril Robert Fletcher, Norman Keith Ayliffe Gardner (from Student), Cyril Aubrey Glew (from Student), Hugh Arthur Goldsmith, Leonard Hagger, John Martin Hare, Henry Hok-Yong Wong, Victor Hollingworth, Norman Horwood,

Derek Howarth (from Student), James Michael Howe (from Student), Joseph Howieson, David George Hurley, Charles Edgar Probert Jackson, Windham Morgan John, John Brodie Bowman Johnston (from Student), Richard Stanton Jones, Derek Howard Jubb, Jaan Alfred Laurmann, Ian Colin Morton, Peter Jack Palmer (ex-Student), Clarence Herbert Perry, Wilfred George Paskins, Eric Richardson, Ernest George Henry Rowland, Keith Anthony Rowland, John Ronald Sharp, Neville Anthony Donald Sharvell, Richard George Spencer (from Student), Christopher Staffurth (from Student), Ian Hilary Steels (from Student), Louis John Stephenson (from Student), Clarence Stewart (from Student), Alan James Troughton (from Student), Barry Arthur Tyler, Reginald Utting, David Noel Vincent, Keith Claude Walker, James Henry Wilson (from Student), Reginald William Winch.

Students

Arthur Robert Chandler, Kenneth Ernest Currey, Hugh Oliver Field, Peter Robert Guyett, Ronald Wheeler Harrison, Eric Leonard Hassell, Graham Hills, Ronald Ian Hodder, Solomon Kehela, Geoffrey Francis Langdon, Philip Reed Miller, Malcomb Christison Muir, David Nowell, Peter Frederick Orchard, Thomas James Patrick, John Pickles, John Dennis Poole, Geoffrey Norman Thayne, Geoffrey Edmund Salt, Stanley Joseph Sealey, Michael George Simpson, George Barclay Scott, Kenneth Edmund Southwood, Ronald Wilks.

Companion

Francis Arthur Butters.

APRIL 1950

Associate Fellows

Charles Frederick Nellthorpe, Robert Emmanuel Moger, Herbert Henry Wakinson (from Associate).

Associates

Woulfe Hay Hicks, Frederick Arthur Jolly, Clarence Hamilton McVeigh, William Frederick Stevens.

Graduates

Beryl Mary Bigg, Peter George Bullen (from Student), Peter Field, John Dennis Leyland Gregory, Brian Aubrey Harding, Hubert William Henry Harding, Peter John Harvey (from Student), Francis Farrell Heaton (from Student), Guy Thornton Smith (from Student), Ronald John Stephens, Edward Philip Vaughan, Brian Hawley Wager (from Student).

Companion

John Cranfurd Powell.

MAY 1950

Associate Fellows

Kenneth John Powell, Frank Myles Temple Reilly, John Seddon.

Associates

Cecil David Melville Kingsford, Henrey William Owen, Richard Woollaston Parr, John Horace Evelyn Numa Rahr, Arthur John Smaill.

Graduates

Francis Edgar Bartholomew, William Alan Fox, George Frederick Gilmore, John Charles Hodge, Kenneth Brian Jepson, Raymond Leslie Wheeler.

JUNE 1950

Associate Fellows

Donald Charles Allen (from Associate), Nora Helen Atkin (from Graduate), Neil William Vincent Barford, Gilbert Edward Barrett, Cecil Baxter, Gordon Day Bennett, Allan Bond, Eric Lewis Bond, Arthur Ronald Butler (from Associate), Jasper Stephen Butcher (from Graduate), Alfred Neil Byron, Patrick James Campbell (from Student), Thomas Martin Chalmers (from Graduate), John Chambers, Francis Victor Davies (from Graduate), Ivan Francis Robert Dickinson, Frank Augustus Drayton, Peter William Dryland (from Graduate), John Leon Edwards, Reginald George Evans (from Graduate), Frank Fallon, Donald Osborne Finlay, John Foley (from Graduate), Lawrence Harry Gould (from Graduate), Peter Grootenhuis; Terence Michael Hainsselin (from Associate), Derek James Hardy (from Graduate), Kenneth Lewis Hodkinson (from Graduate), Maurice Holt, Reginald Eric Hooson (from Student), Kay Hunter, Charles Alan Judson, Norman Frederick Lamb (from Associate), Gerard Niels Louw, Lyndon George McFarlane, Francis Maguiness, William Stanley Donald Marshall (from Graduate), James Allan Mollison (from Associate), Ronald Richard William Moss (from Graduate), William George Moth (from Graduate), Hubert Leslie Peddle (from Associate), George William Perrett, George Harry Hugh Powell, John Henry Powle (ex-Assoc. Fellow), George Ritson Raisbeck, Stanley Edward Richardson (from Graduate), Walter Ralph Roberts, Harry Edgar William Robinson (from Associate), Harry Desmond Rylands, Christopher Scruton, Frederick Charles Slaughter (from Associate), Ernest Edward Smith (from Graduate), Leonard Stanley Snell, John James Spiliman (from Graduate), Antony David Stannard, John Anthony Staunton (from Graduate), Derrick Edward Joseph Tipping (from Graduate), Barry Trodd, Joan Trouncer, Norman Turner, Harold Alexander Vlies, David James Noel Wakeling, William Joseph Walker (from Graduate), George Victor Watson, Victor Willis (from Graduate), Philip John Wingham (from Student), James Wood, Charles George Woolven (from Graduate).

Associates

Arthur Ernest Ronald Broomfield, Percy Brown, George Alex Henry Eckles, James Peter Hamilton, Michael Alrick Josselyn Morton Hayward (from Graduate), Garfield Nathan Tarbet Hemmings (from Student), Stanislaw Jordon, Frank Kirk, Ian McLaren, Louis Wilfred Morton, Harold James Mossman, William Arthur Pendlebury, Frank Edward Pickles, Jean Gaston Pradal, Herbert John Rix, Reginald Louis Secker, Douglas Ramiro Walls (from Student).

Graduates

John Barker, Cyril Frank Blanks, Brian Edward Boyce (from Student), Claude Walter Brenner, Arthur John Cable (from Student), Ralph Cartwright, John Cyril Chaplin (from Student), Walter Edwin Coe, Maurice Jacob Cohen, William Stevenson Cunningham (from Student), Frederick Eric Deudney (from Student), James Philip Graham, Lewis Henry Wilson Harris (from Student), Dennis Alec Head, Gordon Sinclair Henderson, Raymond Derek Hillary, John Dennis Hodge (from Student), Peter Lionel Hughes (from Student), Roy Vernon Hurrell, Leon Bridge Jakens, Royle Bernard Denis Jansen (from Student), Johannes Lie (from Student), Donald Thomas Lincoln, Alastair Munro Mackie (from Student), John Dennis Micklem (from Student), Charles Alan Mitton, Eric Norman-Wilson (from Student), Charles Roy Pratt-Barlow (from Student), Donald Reeves, John Morton Spong (from Student), Robert Graham Taylor (from Student), John Derek Tearle (from Student), Lionel Mervyn Treleman, Jerzy Maciej Tusiewicz, Waldemar Warhaftig, Eric Enos Watts, John Bernard Wellingham, David Douglas Williams, Archibald William Alfred Prott Wilson (from Companion), Malcolm Clow Wilson, Neville Henry Wood (from Student).

Students

Richard John Adams, Philip Charles Aldridge, Allan Blair Bailey, John Charles Arthur Baldock, John Michael Beaumont, John Andrew Dennis Bradshaw, Philip

Arthur Brown, Trevor Percival Brown, David Pierce Comley, Robin Ellis Cooper, Frederick Creedy, Philip Morgan Davey, Ronald John Frost, Dennis Gerald Cave Goodhead, Brian John Griffin, Gerald Kenneth Hunt, Jean Marie Antoine Joseph Jehin, Bhawani Shanker Kaushik, John Edmund Lidiard, John A. Locke, Donald Rex Manning, John Alfred Bowman May, Thomas William Nicholls, Donald Pierrepont, Derek Jess Wilton Richards, John Francis Richards, Alan George Robertson, Leonard James Rogers, Dennis William Taylor, Keith Harold William Tomlin, John Arthur Tucker, Terence David Ward, Jeremy George Waycott.

Companions

Essayed Selim Elmolla.

JULY 1950

Associate Fellows

Alan Richard Buley (from Graduate), Alexander John Chivers (from Student), Lindsay Grahame Dawson, Robert Reginald Dexter, Shirley Donald Dickins (from Associate), Alan Victor Garrett (from Graduate), Terence Hilary Weller Gibbons, Frank Robinson Heath, Harold Hodkinson, Albert George Hurn, Frederick John Kemp, Arthur Charles Leftley (from Graduate), John Magson (from Graduate), Raymond Baird Maloy, S. Krishnaswami Rao, Frederick Victor Rehill (from Associate), Ralph Darkin Williams (from Graduate), William Henry Wittrick, Frank Sutcliffe Wood.

Associates

Adolf Frederick William Andren, Alfred James Barnard, Johanan Barsela, Alfred William Charles Cherritt, Victor Harold Davey, Andrew Graham Gerrand, Albert Henry Hall, Sidney Rufus Nicholson, Samuel David Thomas (from Student).

Graduates

Philip Bruce Atkins (from Student), Alan Avery Blythe (from Student), Geoffrey Percival Dollimore (from Student), David Bruce Elkman, John Cecil Martin (from Student), John Leslie Milne, Frank David Moore, Eric Phillip Potter, Francis George Walker, Henry Robert Warren, Muhammad Akbar Yusuf.

Students

Victor Stanley Chambers, Reginald Mark Diamond, Derek Lionel Augustus Hand, Khurshed Rustomji Khory, Soli Kaikhushru Sahiar, Peter Heron Winter, Paul Irving Woodruff.

AUGUST 1950

Associate Fellows

David Offord Buxton, Neville Lewis Fakes (from Graduate), Thiruvalam Kumaraswamy Srinivasa Murthy (from Companion), Arthur Denis Wood (from Graduate).

Associates

Richard Bruce Bolt, Arthur Leslie Briskham, Patrick Bernard George Davies, Albert William Gregg, Ronald Joseph Leonard, Ronald Albert Read, Geoffrey Newland Roberts.

Graduates

David Eric Chandler (from Student), Kenneth Sydney Robert Child (from Student), Daniel John Holding (from Student), John Shaw Hollings, Roff Taylor Jones, Thomas Henry Kerr, Frederick Claude Kinchela (from Student), Kenneth David Little, Kenneth John Mackenzie (from Student), Adam Merton, Peter Milns (from Student), Raymond Peter Murdoch, Derrick George Murkett (from Student),

Christopher Lawrence Paice (from Student), Frederick Arthur Alfred Palmer (from Student), Mohamed Saeed, Ramon Schoenberg, Frank Arthur Spong, Denis Sword Whitehead.

Students

David Reginald Ashover, Adrian Roger Ian Austin, Walter Bergwerk, Alan John Billington, Hubert Benoit Jacques De'Jardin, Alfred Laws, David William McCulloch, David Needham, Allan John Noon, Douglas William Pedrick, Reginald Harold Platt, Charles Bernard Pollock, Edward John Scanes, Bir Indra Singh, Harold Lloyd Wood.

SEPTEMBER 1950

Associate Fellows

Peter Vince Brown (from Graduate), Herbert Kenneth Cartwright (from Associate), Alfred Dennis Jackson (from Graduate), Charles Dudley Langley, John Lawrence Mort (from Student), Lawrence Wynn Richards (from Graduate), Mufti Mohammad Salim, Richard Thomas Courtenay Satterford (from Graduate), Reginald William Taylor, Charles Edward Tharratt.

Associates

James Newman Angless, Peter William Armitage, Edwin George Barber, Walter Raymond Carus, Arthur Bernard Cooper, Charles Quintin De Souza, William Joseph Dowler, Donovan John Flood, Gilbert Hawkyard, George Winzar Horne (from Companion), Arthur Henry Kerr, Jack Eric Lauderdale, Francis John Low (from Student), John Cecil Miles, Franklin Barry Morley, Andrew Derek Munro (from Student), Eric Ranson Murray (from Student), Colin Vernon Olver.

Graduates

Douglas Francis Beanland (from Student), David Dunbar Carrow (from Student), Frederick James Edwards, Arthur Kenneth Hathway, Graham Basil Hustings, William Robert Antony James, Dalbir Kumar Kapur (from Student), Charles Philip Smith, Richard Joseph Wickens.

Students

Peter Ernest Ayre, Edward Thomas Curran, Derek Reaney, Iqbal Shoaib, Paul Simpkin, John Graham Wakeford, David Howard Warren.

Companion

William Armistead Moale Burden.

OCTOBER 1950

Associate Fellows

Robert Elkan Landau (from Graduate), Colin Philip Lindsay Nicholson, William Haughton Pritchard, Basil Ernest Stephenson, John Williams.

Associates

George Whelan Acock, John Bernard Neate Coles, Edward Arthur Dewhirst, Gerald Clifford Frewer, Norman Kearl, Bernard Charles Phillips, Frederick Sydney Staples.

Graduate

Geoffrey St. Quintin Crockett (from Student).

Students

Derek Brickenden, Robert Edward Catterwell, Louis Burton Irving, Edwin John Knight, Brian John Van De Water, John Steele Wright.

NOVEMBER 1950

Associate Fellows

George Robert Allison (from Associate), Nelson William Maclean Beatts, James Francis Berry (from Graduate), Ronald John Brocklehurst (from Graduate), Kevin Edmunds Cheverton (from Graduate), Francis Jeffrey Colville (from Graduate), Leslie Frank Compton, William Fisher, William Anthony Walter Fox, Frederick Hodson, Dennis Albert Logan (from Graduate), Alan Bycroft Lowe (from Graduate), Jag Nath Mathur, Robert Hellyar Perrott (ex-Graduate), John Clifford Pope, Ian Wedderburn Clunie Robertson (from Graduate), Harold Martin Russel, Alec Simon, Sidney John Smith (from Graduate), Kenneth George Standell (from Graduate), Raymond Kenneth Peter Stevens (from Graduate), Charles Leonard Trevithick (from Associate), Edward Elijah Weekley (from Associate), Maurice Oliver Wilmer (from Graduate), Ronald Anderson Wood, Ivor Edward Woodroffe (from Graduate), Peter William Wreford-Bush (from Graduate), Dennis Wright (from Graduate).

Associates

William Gordon Bailey, John Robert Batt, Peter Kenneth Brack, Frank Brookesmith, Leonard Ernest Bunnett, William Burley, Reginald Arthur Coates, Sidney Arthur Cooper, Patrick Jerard Crowley, William Thomas Elson, John Foster Ferguson, Richard Albert Fuller, Ronald Basil Griffiths, John Harston, Frederick Maurice McGregor, Nelson William Maskell, Thomas Sivewright Middleton, Bertram Arthur Morris, Peter Hugh Raymond, Robert James Varner Russell, Graham Robertson Stroud, Reginald Vaughan Grant Tunstall, John Ashworth Tupman (from Student), Victor Alfred Vagg, Gerald Edward Wills, Norman David Wolf, John Wood-Collins.

Graduates

Clifford John Benjamin (from Student), John Nobel Cochrane, David John Cockrell, Arthur Haydon Craven, Eric Leonard Hassell (from Student), George Hughes, Donald Roy Lewis, Andrew Colin Nicholls, Edward Norman Palmer, John Thomas Pratt, Alan Hugh Stenning (from Student), Robert Keith Turton, John Walker, Arthur Frank Albert Watts (from Student).

Students

Richard Durnford, Gerald William East, Jack Womersley Headley, Peter Kennett, Joseph William Herbert Dennis Lovell, Michael Martin Marsh, Zdenek A. Navratil, Harold Alexander Simon, Peter Hubert Swift, John Edward Wingate, Krishna Murthy Narayana Murthy Yellhanka.

Companion

Sobhi Ahmed Ali.

DECEMBER 1950

Associate Fellows

William Alexander Beedie (from Student), Raymond Percy Bonham, Kenneth Arthur Joseph Foord (from Graduate), Samuel Paul Johnston, Robert Maximilian Kenedi, Henry Morgan, Kenneth Raymond Nuttall (from Graduate), Colin Winterbotham Weedon, Derek Victor Wordsworth (ex-Assoc. Fellow).

Associates

Henry Horace Cadman, Maurice Reginald Chantrill, Ronald Evans, William James Flake, George Joseph McTigue, Leslie Roberts, Frederick William Sainsbury, Harold West, James Winward, Peter Alan Woolf.

Graduates

Josef Aretz (from Student), Percy Geoffrey Ball (from Student), Antony Chinneck, John Grigor, Ronald Charles Harris (from Student), Stephen John Taylor Harvey (from Student), David Arundel Yeo O'Clarey (from Student),

Edmund Archdale Palmer, John Norman Quick, Geoffrey Cowie Sugden (from Student), Francis Robert Ward.

Students

Bernard Arthur Bridges, Shin Lan Chan, Peter John Elmes, Derek Alexeis Horton, Eric Antony Robert Humpston, William Dennis Sproson, Peter Appleby Trotman, Robert Desmond Ward, Denis Edward Weeding, Patricia June Wilson.

Companions

Nasir Ali, Arthur Herman Brown.

ASSOCIATE FELLOWSHIP EXAMINATIONS RESULTS

The following were successful in the Associate Fellowship Examinations held in December 1949:—

HOME

G. E. L. Abbott, Aircraft Materials; F. R. Aiway, Theory of Machines; J. J. Ansell, Strength of Materials; J. Aretz, Strength of Materials, Theory of Machines, C. R. Pratt-Barlow, Strength of Materials; J. C. Barrett, Aerodynamics; W. A. Beedie, Theory of I.C. Engines, Aircraft Instruments; P. P, Benham, Theory of Machines; D. Biltcliffe, Aircraft Materials; A. A. Blythe, Design (Aircraft); R. A. Blythe, Aircraft Materials; G. Bond, Aircraft Instruments; S. F. Borrie, Pure Mathematics, Design (Aircraft); B. E. Boyce, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; C. R. Broughton, Pure Mathematics; D. W. Bryer, Aerodynamics; J. Bunting, Strength of Materials; D. M. Burke, Aircraft Materials; W. Burley, Aerodynamics; B. Buss, Theory of Machines, Design (Aircraft).

J. A. Caister, Pure Mathematics; H. K. Cartwright, Meteorology—1st Place; J. C. Chaplin, Pure Mathematics, Aerodynamics—1st Place, Design (Aircraft)—1st Place; D. G. Clark, Pure Mathematics, Design (Aircraft); C. E. Clinch, Applied Mathematics; W. E. Coe, Aerodynamics; P. J. Colbourne, Applied Mathematics; L. F. Compton, Applied Mathematics, Theory of Machines, Aircraft Instruments—1st Place; J. E. Cresswell, Pure Mathematics; G. St. Q. Crockett, Strength of Materials; R. H. Cross, Pure Mathematics, Theory of Machines.

I. J. Davies, Strength of Materials; G. P. Dollimore, Pure Mathematics, Design (Aircraft); P. C. Donovan, Strength of Materials.

R. W. Edwards, Theory of I.C. Engines, Theory of Machines; P. P. Elliott, Aerodynamics.

T. M. Fitz-Gibbon, Design (Aircraft); E. Fryer, Theory of I.C. Engines, Design (Aero Engines); R. A. Fuller, Applied Mathematics, Theory of I.C. Engines—1st Place, Design (Aero Engines).

J. R. Gardiner, Applied Mathematics, Theory of Machines, Aircraft Materials; N. Ghose, Strength of Materials; B. M. Goldsmith, Strength of Materials, Aircraft Materials; F. Gowens, Theory of I.C. Engines, Theory of Machines; A. W. Gray, Theory of I.C. Engines, Design (Aero Engines); G. K. F. Green, Strength of Materials; J. R. Green, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; E. A. Greenwood, Applied Mathematics—1st Place, Theory of Machines; B. J. Griffin, Applied Mathematics, Theory of I.C. Engines, Theory of Machines—1st Place; J. Grigor, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; J. Grossman, Theory of I.C. Engines.

R. H. Hadcock, Pure Mathematics; S. D. Hall, Theory of Machines; L. H. W. Harris, Aerodynamics; J. T. Hawken, Theory of Machines; T. H. J. Heffernan, Aerodynamics; R. D. Hillary, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; K. G. Hodson, Pure Mathematics; D. H. Hughes, Design (Aero Engines); P. L. Hughes, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; J. H. Hurford, Theory of I.C. Engines.

F. Jackson, Theory of Machines; W. R. A. James, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; R. B. D. Jansen, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; C. H. Johns, Pure Mathematics, Strength of Materials, Design (Aircraft); F/Lt. F. A. Johnson, Design (Aircraft).

D. K. Kapur, Theory of I.C. Engines, Theory of Machines; R. N. Kashyap, Design (Aircraft); W. J. Kenyon, Pure Mathematics, M. Kishor, Meteorology; R. G. Knight, Applied Mathematics; J. Koslowski, Applied Mathematics, Theory of Machines.

R. H. Ladd, Applied Mathematics, Theory of Machines; J. A. B. Lambert, Strength of Materials, Aerodynamics; B. Landi, Pure Mathematics; C. D. Langley, Aerodynamics; J. H. Lewendon, Applied Mathematics, Theory of Machines; J. Lie, Theory of I.C. Engines, Theory of Machines, Air Transport; D. J. Lincoln, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; J. J. Lindsay, Aerodynamics, Design (Aircraft).

J. E. Mack, Strength of Materials; K. J. Mackenzie, Theory of I.C. Engines; P. McLaughlin, Aircraft Materials; W. McPherson, Theory of Machines; C. H. Martin, Strength of Materials, Design (Aircraft); G. E. Martin, Pure Mathematics; D. T. A. Miller, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; A. J. L. Mitchell, Theory of I.C. Engines, Design (Aero Engines); J. L. Mort, Strength of Materials; K. K. Mukerjee, Theory of I.C. Engines, Theory of Machines; R. P. Murdoch, Pure Mathematics, Aerodynamics.

J. Nash, Applied Mathematics; T. W. Nicholls, Applied Mathematics, Theory of I.C. Engines, Theory of Machines.

T. O'Brien, Theory of I.C. Engines, Aircraft Materials; A. M. G. Olsen, Theory of I.C. Engines, Theory of Machines; B. O'Reilly, Aircraft Materials; J. L. O'Reilly, Theory of I.C. Engines, Design (Aero Engines); R. T. P. O'Shea, Aircraft Materials.

J. A. Padilla, Design (Aircraft); P. R. Philpot, Strength of Materials; E. P. Potter, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; R. G. Prasad, Pure Mathematics; J. Pratt, Theory of I.C. Engines, Theory of Machines; W. H. Pritchard, Applied Mathematics, Theory of Machines; F. J. B. Purchase, Applied Mathematics, Theory of Machines.

J. M. Ramsden, Aerodynamics; S. Ranjan, Pure Mathematics; D. Reaney, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; D. Reeves, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; G. Reynard, Pure Mathematics, Theory of I.C. Engines; N. W Ridgway, Aircraft Materials—1st Place; J. M. Roberts, Pure Mathematics, Strength of Materials; K. M. Roche, Theory of I.C. Engines; S. T. Roed, Aerodynamics; H. N. Roy, Theory of Machines.

Mohamed Saeed, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; A. J. Salmon, Theory of I.C. Engines, Design (Aero Engines)—1st Place —Tie; R. L. Samuels, Applied Mathematics, Theory of I.C. Engines; S. R. Sarrailhe, Pure Mathematics, Strength of Materials, Theory of Machines; R. Schoenberg, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; R. L. Secker, Aerodynamics, Aircraft Materials; E. G. F. Da Silva, Applied Mathematics, Theory of I.C. Engines, Theory of Machines; K. M. Smith, Applied Mathematics, Aircraft Materials; F. M. Soonawalla, Pure Mathematics, Theory of I.C. Engines; M. E. L. Spanyol, Aerodynamics; J. P. Spillane, Design (Aero Engines); J. M. Spong, Theory of I.C. Engines; G. N. Srivastava, Theory of I.C. Engines, G. C. Sugden, Theory of I.C. Engines; I. A. Syed, Pure Mathematics.

C. E. Tharratt, Theory of I.C. Engines; J. M. Thurston, Theory of I.C. Engines, Design (Aero Engines).

R. W. Usher, Applied Mathematics, Theory of Machines.

E. Vezyriandis, Applied Mathematics, Theory of Machines.

J. G. Wakeford, Theory of Machines; J. Walker, Applied Mathematics, Theory of Machines, Theory of I.C. Engines; W. Warhaftig, Applied Mathematics; D. W. Warne, Theory of I.C. Engines, Design (Aero Engines); J. B. Wellingham, Theory of Machines, Wireless Telegraphy; C. R. J. Whitfield, Theory of I.C. Engines, Theory of Machines; R. J. Wickens, Pure Mathematics; C. W. Williamson, Aircraft Materials; A. Winyard, Theory of Machines; P. A. Woolf, Theory of Machines; J. Wyatt, Design (Aircraft).

NEW SYLLABUS

F. C. Hanbury, Theory of Prime Movers and Fuels; B. M. Laven, Properties of Matter. Heat, Light and Sound.

ABROAD

The following candidates were successful in the December 1949 Examinations held abroad:—

C. G. Andrews (Wellington), Aerodynamics.

R. N. Banerjee (Aligarh), Theory of Machines; S. R. Bhattacharya (Calcutta), Design (Aero Engines); W. J. Bouma (Amsterdam), Applied Mathematics, Aerodynamics.

P. C. Gassin (Calcutta), Theory of Machines; B. K. Ghosh (Jodhpur), Pure Mathematics—1st Place, Theory of I.C. Engines, Navigation—1st Place; R. S. Gopalachar (Bangalore), Design (Aircraft).

S. V. Karandikar (Bombay), Aircraft Instruments; F/Lt. V. Kumar (Kanpur), Theory of Machines, Air Transport.

E. H. Law (Auckland), Strength of Materials, Aircraft Materials; Sgt. P. Long, Design (Aero Engines).

Lt. (E) A. J. Macdonald, Theory of Machines; J. McDonald (Sydney), Pure Mathematics, Aerodynamics, Navigation; J. N. Mathur (Bombay), Theory of I.C. Engines.

C. P. L. Nicholson (Ottawa), Theory of I.C. Engines.

A/A. F. A. A. Palmer, Design (Aero Engines)—1st Place—Tie; C. S. Patro (Bangalore), Pure Mathematics; K. C. Pradhan (Gwalior), Pure Mathematics.

W. Raj (East Punjab), Theory of I.C. Engines; C. Rajagopal (Bangalore), Aerodynamics, Design (Aircraft); J. Rosenthal (Melbourne), Theory of Machines; G. H. Ryning (Toronto), Aircraft Materials.

B. Singh (Nagpur), Air Transport; P. Singh (Kanpur), Design (Aero Engines), L. P. Sinha (Allahabad), Design (Aero Engines); F/Sgt. N. V. Slatter, Theory of I.C. Engines, Design (Aero Engines).

L. G. Thomas (Calgary), Aircraft Materials; L. M. Treleman (Toronto), Strength of Materials.

S. Zafar (Allahabad), Theory of I.C. Engines.

The following were successful in the Associate Fellowship Examinations (New Syllabus) held in May 1950:—

PART I (HOME)

J. A. H. Bailie, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; A. D. Balmain, Theory of Prime Movers and Fuels.

G. H. Fenton, Pure Mathematics, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

B. T. Lewis, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

L. F. Nicholls, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

G. S. Pool, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Strength of Aircraft Materials and Theory of Structures I.

D. Rowe, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

G. A. C. Searle, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; P. W. Shaw, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I; J. Sylvanus, Strength of Aircraft Materials and Theory of Structures I.

M. J. Taylor, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

E. G. Wilkinson, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

W. A. Zaremba, Pure Mathematics, Properties of Matter, Heat, Light and Sound, Strength of Aircraft Materials and Theory of Structures I, Theory of Machines.

(ABROAD)

W. R. Burge (Canada), Pure Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

A. F. El-Kerdani (Egypt), Pure Mathematics, Aerodynamics I, Strength of Aircraft Materials and Theory of Structures I.

PART II (HOME)

A. C. Brown, Aerodynamics II; B. R. A. Burns, Aerodynamics II.
D. E. Gladwin, Aerodynamics II; W. A. Pollard, Aerodynamics II.
A. J. Scarr, Aerodynamics II; H. N. Saint, Aerodynamics II.

The following candidates were successful in their final subjects in the Associate Fellowship Examination held in August 1950 under the old syllabus:—

P. P. Benham
B. Buss
J. A. Caister
I. J. Davies
R. W. Edwards
P. P. Elliott
E. Fryer
B. M. Goldsmith
F. Gowens
A. W. Gray
E. A. Greenwood
R. N. Hadcock
W. E. Hagan (Montreal)
S. D. Hall
J. T. Hawken
T. H. J. Heffernan
D. H. Hughes
J. H. Hurford
Cpl. W. G. Johnson (Ceylon)
F/Lt. F. A. Johnson
M. Kishor
R. G. Knight
J. A. Kozlowski
R. H. Ladd
W. W. Lewis
J. M. Lewendon
Sgt. P. Long (M.E.F.)
J. E. Mack
H. J. F. Manners
C. H. Martin
J. Nash
D. Naylor
Miss J. M. Nelmes
N. N. Nicholls
A. M. G. Olsen
J. L. O'Reilly (Nigeria)
B. G. Cour-Palais
C. S. Patro (Bangalore)
J. W. Paulsen (Norway)
R. G. Prasad
C. Rajagopal (Bangalore)
H. N. Roy
A. J. Salmon
R. L. Samuels
D. Shellard
L. J. A. Sice
B. Singh (Nagpur)
F/Sgt. N. V. Slatter (Malaya)
F. M. Soonawalla
G. N. Srivastava
T. V. Trinder (S. Africa)
E. Vezyrianidis
D. W. Warne
K. R. Warren
C. R. J. Whitfield
K. F. Wood
J. Wyatt

WILBUR WRIGHT MEMORIAL LECTURE

The 38th Wilbur Wright Memorial Lecture was read on Thursday, 25th May 1950, by Sir Richard Fairey, M.B.E., F.R.Ae.S., on "Some Aspects of Expenditure on Aviation." The complete report was published in the July 1950 JOURNAL.

LOUIS BLERIOT LECTURE

The Third Louis Bleriot Lecture was read in Paris on Thursday, 4th May 1950, By Sir Frederick Handley Page, Hon. Fellow. The title of the Lecture was "Towards Slower and Safer Flying, Improved Take-Off and Landing, and Cheaper Airports." A complete report was published in the December 1950 JOURNAL.

BRITISH COMMONWEALTH AND EMPIRE LECTURE

The Sixth British Commonwealth and Empire Lecture was given on Thursday 28th September 1950 by Sir George Cribbett, K.B.E., C.M.G., Deputy Secretary, Ministry of Civil Aviation, on "Some International Aspects of Air Transport with Particular Reference to Future Aircraft Operation." A complete report was published in the November 1950 JOURNAL.

LECTURES 1950

MAIN LECTURES (At the Institution of Civil Engineers)

9th February—The Producing of a Prototype Aircraft, C. T. Wilkins, A.F.R.Ae.S.

2nd March—Design for Maintenance, R. E. Bishop, C.B.E., F.R.Ae.S.

16th March—Air Survey, the Application of Modern Techniques to Surveying and Mapping, Prof. C. A. Hart, M.Sc.(Eng.), Ph.D., M.Inst.C.E., F.R.I.C.S.

30th March—Modern Methods of Testing Aero-Engines and Power Plants, A. C. Lovesey, O.B.E., B.Sc., F.R.Ae.S.

13th April—The Berlin Air Lift, Air Commodore J. W. F. Merer, C.B.

27th April—At Manchester—Recent Developments in High Speed Research in the Aerodynamics Division of the N.P.L., J. A. Beavan, M.A.(Cantab), A.F.R.Ae.S., and D. W. Holder, D.I.C., A.C.G.I., B.Sc.

4th May—3rd Louis Bleriot Lecture—In Paris: Towards Slower and Safer Flying, Improved Take-Off and Landing, and Cheaper Airports, Sir Frederick Handley Page, C.B.E., F.I.Ae.S., Hon.F.R.Ae.S.

25th May—38th Wilbur Wright Memorial Lecture: Some Aspects of Expenditure on Aviation, Sir Richard Fairey, M.B.E., Hon.F.R.Ae.S.—*at the Royal Institution.*

28th September—6th British Commonwealth and Empire Lecture: Some International Aspects of Air Transport, Sir George Cribbett, K.B.E., C.M.G.

19th October—Use of Wind Tunnel Model Data in Aerodynamic Design, R. Hills, B.A., A.F.R.Ae.S.

7th November—At Belfast—Aircraft Metallic Materials under Low Temperature Conditions, Major P. L. Teed, F.R.Ae.S.

23rd November—Rockets and Assisted Take-Off, A. V. Cleaver, A.R.Ae.S.

7th December—A Discussion—The Relative Merits of Centrifugal and Axial Compressors for Aircraft Gas Turbines, H. Pearson, B.A., A.F.R.Ae.S., and Dr. E. S. Moult, B.Sc., F.R.Ae.S., M.I.Mech.E.

14th December—Clear Air Turbulence Over Europe, Dr. G. S. Hislop, B.Sc., A.R.T.C., M.I.Mech.E., A.F.R.Ae.S.

SECTION LECTURES (In the Library, 4 Hamilton Place, London, W.1)

19th January—Joint Section Lecture with the Acoustics Group of the Physical Society—Acoustical Aspects of Recent Aerodynamic Research.
Short Lectures on: Supersonic Noise of Aircraft, N. Fleming, M.A.
Noise and Vibration in Wind Tunnels, H. B. Squire, M.A., F.R.Ae.S.
Periodic Boundary Layers, Dr. E. G. Richardson, B.A., D.Sc.
Acoustic Analogues in Calculating Supersonic Resistance, A. Robinson, M.Sc., A.F.R.Ae.S.

31st January—Further Problems of Aircraft Stressing, J. H. Argyris, A.F.R.Ae.S.

14th February—Prototype Testing of Aircraft, D. R. H. Dickinson, A.F.R.Ae.S.

21st February—Air Intake Design for High Speed Aircraft, Dr. J. Seddon, B.Sc.

21st March—Boundary Layer at High Speeds, A. D. Young, M.A., A.F.R.Ae.S.

25th April—Flight Refuelling and the Problem of Range, C. H. Latimer Needham, M.Sc., F.R.Ae.S.

10th October—Problems of High-Speed Flight, G. T. R. Hill, M.C., M.Sc., F.R.Ae.S., M.I.Mech.E.

24th October—Aircraft Riveting, H. Giddings, A.F.R.Ae.S.

14th November—Operational Problems of Public Transport Helicopters, R. H. Whitby, B.Sc., A.R.C.S., D.I.C., A.F.R.Ae.S.

28th November—Metal Adhesive Processes, F. H. Parker.

5th December—Aircraft Production, Prof. J. V. Connolly, B.Eng., F.R.Ae.S.

BRANCH LECTURES AND ACTIVITIES

BELFAST BRANCH

24th January—Recent Developments in Aircraft Production Engineering, Prof. J. V. Connolly, B.Eng., F.R.Ae.S.
14th March—Problems of High Speed Flight, H. Davies, M.Sc., F.R.Ae.S.
4th April—Annual General Meeting.
3rd October—Industrial Applications of the Gas Turbine, G. L. Duffett, M.A.
7th November—Main Lecture: Aircraft Metallic Materials Under Low Temperature Conditions, Major P. L. Teed, A.R.S.M., M.I.M.M., F.R.Ae.S.
12th December—Boundary Layers at High Speeds, Prof. A. D. Young, M.A., A.F.R.Ae.S.

BIRMINGHAM BRANCH

6th January—Annual Dinner.
27th January—Inter-Planetary Flight and Rocket Propulsion, A. V. Cleaver, A.R.Ae.S.
24th February—A Chat on Aero-Engines, Air Commodore F. R. Banks, C.B., F.R.Ae.S.
31st March—President's Night, Dr. S. C. Redshaw, F.R.Ae.S.
21st April—Annual General Meeting and Smoking Concert.
25th September—Visit to Boulton Paul Aircraft Ltd., Wolverhampton.
27th October—A Discussion on Aeronautical Experiences—led by Messrs. Baldwin, Garrat-Reed, Yoxall and Bostock.
24th November—A Review of Aerodynamic Cleanness, Prof. E. J. Richards, M.A., B.Sc., F.R.Ae.S.
15th December—Radar and Kindred Pilot Aids.

BRISTOL BRANCH

16th January—Operational Factors Affecting the Design of Future Civil Air Transport Aircraft, C. Dykes, M.A., A.F.R.Ae.S.
30th January—Bird Flight, Prof. H. B. Passat.
13th February—Aerial Photography, Group Captain F. C. V. Laws, C.B., C.B.E.
27th February—The Role of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.
13th March—Junior Members' Papers Competition.
27th March—Gliding, A. H. Yates, B.Sc., A.F.R.Ae.S.
5th April—Recent Developments in Aircraft Production and Engineering, Prof. J. V. Connolly, B.Eng., A.F.R.Ae.S.
24th April—Annual General Meeting and Film Show.
23rd October—Forty Years of British Aviation, Sir Frederick Handley Page, C.B.E., Hon.F.R.Ae.S., F.C.G.I.
31st October—Some Problems in Helicopter Aerodynamics, W. Stewart, B.Sc.
15th November—Present Trends of Industrial Gas Turbine Development, R. G. Voysey, A.C.G.I., D.I.C., Wh.Sc., A.M.I.Mech.E.—*Joint Meeting with the Institutions of Mechanical and Electrical Engineers.*
27th November—Section Lecture: Landing Gear Design, H. G. Conway, M.A., F.R.Ae.S., A.M.I.Mech.E.
4th December—Physical Aspects of Compressible Flow and Shock Waves, Joseph Black, M.Sc., A.F.R.Ae.S.

BROUGH BRANCH

11th January—Members' Lecturette Night.
8th February—Rocket Propulsion and Interplanetary Flight, A. V. Cleaver, A.R.Ae.S.
5th April—Design Problems of the Flying Boat, H. Knowler, F.R.Ae.S., A.M.I.C.E.

13th September—Space Stations, E. Burgess.
11th October—The Mamba Engine, J. Marlow.
15th November—The Role of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.
6th December—Members' Lecturette Night.

COVENTRY BRANCH

18th January—High Speed Flight, A. D. Young, A.F.R.Ae.S.
15th February—The Ghost Engine Installation of the Comet, W. T. Winter.
15th March—Flying Boats, H. Knowler, F.R.Ae.S.
19th April—Annual General Meeting and Films.
20th September—Combustion in the Gas Turbine, S. Allen.
18th October—Rocket Propulsion and Interplanetary Flight, A. V. Cleaver, A.R.Ae.S.
15th November—Flutter, H. Templeton, B.Sc., A.F.R.Ae.S.
13th December—Films.

DERBY BRANCH

3rd April—Modern Methods of Testing Aero-Engines and Power Plants, A. C. Lovesey, O.B.E., B.Sc., F.R.Ae.S.
2nd October—The de Havilland Comet, F. I. Marking and G. Reynard.
6th November—Some Problems of the New Developments in Civil Air Transport Equipment, C. R. Creighton, B.Sc., A.F.R.Ae.S.
4th December—Annual General Meeting and Aeronautical Quiz.

GLASGOW BRANCH

24th January—Debate: Civil Aviation is a Luxury.
21st February—Lecturettes.
23rd March—Fuel Consumption, J. Leggatt, Student R.Ae.S.
18th April—Structural Testing, J. B. B. Owen, B.Sc., A.F.R.Ae.S.
11th September—Maintenance of Aircraft at Out Stations in Scotland, A. Lowe.
17th October—Paper on Engines by a member of the staff of Rolls Royce Ltd.
20th November—Two Films: Aircraft Review for 1949 and Refinery Processes—Gasoline.
15th December—Annual General Meeting.

GLOUCESTER AND CHELTENHAM BRANCH

12th January—At Cheltenham—Recent Developments in Aircraft Production Engineering, Prof. J. V. Connolly, B.Eng., F.R.Ae.S.
8th February—At Gloucester—The Probable Role and Influence of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.
29th March—At Gloucester—Materials of Aircraft Construction and Material Processing, Dr. H. Sutton, D.Sc., F.R.Ae.S., F.I.M.
20th April—At Cheltenham—Annual General Meeting.
22nd November—At Gloucester—Recent Developments in Aircraft Hydraulics, D. P. Amor, B.Sc., A.F.R.Ae.S.
25th November—A visit to the Bristol Aeroplane Co. Ltd.

HATFIELD BRANCH

6th September—The Development and Manufacture of Sound Film Reproducing Equipment, A. L. Whitely.
4th October—Future Development in Aircraft Undercarriages and their Actuating Mechanism, H. G. Conway, M.A., F.R.Ae.S., A.M.I.Mech.E.
1st November—Methods and Construction of The de Havilland 106, S. Rudge.
22nd November—Aviation Medicine, Dr. K. G. Bergin.

ISLE OF WIGHT BRANCH

12th January—Discussion Evening. Control Systems.
26th January—Human Limitation to High Speed, High Altitude Flight, Squadron Leader J. S. Howitt.
23rd February—The Application of Propeller Turbines to Civil Airliners, E. J. Richards, M.A., B.Sc., A.F.R.Ae.S.
9th March—High Speed Research, J. D. Derry.
23rd March—Gliding, P. A. Wills, C.B.E.
12th October—One Thousand Miles an Hour, G. T. R. Hill, M.C., F.R.Ae.S.
1st November—The Principles of Space Flight, A. C. Clarke, B.Sc.
16th November—Junior Brains Trust. Team: E. Aubrey, W. Crago, R. Darroll, F. Davison, D. Hardy. Question Master: F. H. Robertson.
30th November—Aviation Fuels, Lubricants and Special Products, J. R. Bradford.
13th December—Annual General Meeting. How the Birds Learnt to Fly, R. E. F. Potter.

LEICESTER BRANCH

11th January 1950—The Brabazon Aeroplane, Mr. Nash.
15th February 1950—Bird Flight, Professor Passat.
8th March 1950—Welded Magnesium Structures, R. J. Cross.
19th April—Short papers by members.
11th October—Films.
8th November—The Aeroplane as a Commercial Product, Captain K. J. G. Bartlett.
13th December—Research in Civil Aviation, N. E. Rowe, C.B.E., B.Sc., F.R.Ae.S.

LUTON BRANCH

4th January—The Weight Aspect in Aircraft Design, L. W. Rosenthal, A.F.R.Ae.S.
1st February—"The Aeroplane," Thurstan James.
1st March—I.C.A.O. as it Affects the Designer, W. Tye, O.B.E., B.Sc., F.R.Ae.S.
22nd March—Film Show.
5th April—Large Landplanes versus Flying Boats, D. Keith Lucas, B.A., F.R.Ae.S., A.M.I.Mech.E.
3rd May—History of Aeronautics.
24th May—Discussion Evening, Papers presented by Branch members.
6th September—Some Flying Experiences, Wing Commander C. G. B. McClure, A.F.C.
4th October—The Development of the Aero Engine, E. S. Moult, Ph.D., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E.
1st November—Film Show.
22nd November—Discussion Evening, Papers by Branch members.
6th December—Aircraft Maintenance, B. S. Shenstone, M.A.Sc., F.R.Ae.S., A.F.I.Ae.S.
13th December—Annual General Meeting.

MANCHESTER BRANCH

25th January—Civil Air Transport, Present and Future, P. G. Masefield, M.A., F.R.Ae.S.
2nd February—The Role of Aircraft in War and their Probable Influence on the Future, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.
22nd March—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.
25th October—The R.A.E. 1941-1946, W. S. Farren, C.B., M.B.E., M.A., F.R.S., M.I.Mech.E., F.R.Ae.S.

22nd November—Aircraft Electrical Equipment, E. R. Legg.
20th December—A.I.D. Methods of Testing, W. N. Blacklock, A.F.R.Ae.S.

PORTSMOUTH BRANCH

13th January—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.
10th February—Journay to South Africa by Solent Flying-Boat, Geoffrey Dorman, A.R.Ae.S.
10th March—Design Problems of Large Flying-Boats, H. Knowler, F.R.Ae.S.
21st April—The Probable Role and Influence of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.
16th November—Film: Welding Aluminium (Aluminium Development Association).
30th November—Film: Petroleum (Shell Petroleum Co.).
14th December—Film: Oxy-Acetylene Welding (British Oxygen Co.).

PRESTON BRANCH

4th January—Films.
1st February—Defence Against the Flying Bomb, Wing Commander R. P. Beamont, D.S.O., D.F.C., A.R.Ae.S.
22nd February—Radar and the Aircraft Which Use It, B. W. Hodlin, B.Sc.
15th March—Lecturettes, Branch members.
26th April—Annual General Meeting.

READING AND DISTRICT BRANCH

22nd February—An Informal Address on Propeller-Turbines, A. C. Clinton, F.R.Ae.S.
12th April—Flying-Boats, H. Knowler, F.R.Ae.S.
6th October—Railway Civil Engineering Plant, A. G. Ticehurst.
25th October—Fatigue, Major P. L. Teed, F.R.Ae.S.
30th November—Car Design and Testing for Quantity Production, A. F. Houlberg, A.R.Ae.S.

SOUTHAMPTON BRANCH

11th January—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.
22nd February—Some Flying Experiences, Lt.-Cdr. E. M. Brown, O.B.E., D.F.C., M.A., A.F.R.Ae.S.
22nd March—Swept-Back Wings, G. T. R. Hill, M.C., F.R.Ae.S.
11th October—A Review of Aerodynamic Cleanness, Prof. E. J. Richards, M.A., B.Sc., F.R.Ae.S.
1st November—The Principles Underlying the Dynamic Stressing of Aircraft, Dr. D. Williams, A.F.R.Ae.S., M.I.Mech.E.
29th November—The Control of Direct Coupled Gas Turbine Propeller Engines, W. H. Lindsey, M.A., F.R.Ae.S.

WEYBRIDGE BRANCH

11th January—Brains Trust.
20th January—Annual Dance.
8th February—The Aerodynamic Consequences of Flying High and Fast, W. G. A. Perring, C.B., F.R.Ae.S., A.M.I.N.A.
1st March—Do Scientists Know Anything? C. G. Grey, *Founder Member* R.Ae.S.
22nd March—Junior Prize Lecture, Branch members.
31st May—Annual General Meeting.
29th November—A Film Show.
13th December—Designing for High Speed, Prof. E. J. Richards, M.A., B.Sc., F.R.Ae.S.
29th December—Annual Dance.

GRADUATES AND STUDENTS SECTION

The Graduates' and Students' Committee of Council for the year June 1950 to June 1951 is as follows:—

Chairman—J. W. F. Housego (Handley Page Ltd.).

Hon. Secretary—M. C. Campion (The Bristol Aeroplane Co. Ltd. (London)).

Committee Members—S. Scott Hall, *Fellow* (D.G.T.D.(A.), Ministry of Supply), A. V. Cleaver, *Associate* (The de Havilland Engine Co. Ltd.), M. K. Bowden, *Student* (Northampton Engineering College), J. C. Gibbings, *Graduate* (Royal Aircraft Establishment), F. G. Irving, *Graduate* (Imperial College), J. R. Miller, *Graduate* (Hawker Aircraft Ltd.), K. R. Warren, *Student* (The de Havilland Aircraft Co. Ltd.).

LECTURES

23rd February—Some Problems of Heat Transfer, W. R. Shapey, B.Sc., Grad.R.Ae.S., and J. Rivers, Grad.R.Ae.S.

1st March—A. Joint Meeting with the Graduate Sections of the Institution of Electrical Engineers and the Institution of Mechanical Engineers. Some Engineering Problems of Aircraft Design. *This meeting was held at the Institution of Mechanical Engineers, Stoerys Gate, S.W.*1.

7th March—Gas Turbine Installation, J. C. Wallin, B.Sc., A.F.R.Ae.S.

28th March—Undercarriage Design and Testing, G. S. Cranwell, Grad.R.Ae.S.

18th April—A Discussion Evening on the Training of Aeronautical Engineers. Chairman: Marcus Langley, F.R.Ae.S.

5th October—The Technique of Resonance Testing and Flutter Calculations as Applied to Fighter Aircraft Design, C. P. Plantin, B.Sc., A.F.R.Ae.S.

26th October—The Aerodynamics of Compressor and Turbine Cascades, J. A. Dunsby, B.Sc., D.I.C., Grad.R.Ae.S.

9th November—Work in the High-Speed Tunnel, F. G. Irving, B.Eng., Grad.R.Ae.S.

30th November—High-Speed Flying, Squadron Leader J. Derry, D.F.C.

12th December—Film Show, W. Courtenay, O.B.E., M.M., A.R.Ae.S.

HONORARY FELLOWSHIP

The following were awarded Honorary Fellowship of the Society in 1950:—

Robert Blackburn, O.B.E., A.M.Inst.C.E., M.I.Mech.E., M.I.P.E.
Sir Richard Fairey, M.B.E.
T. O. M. Sopwith, C.B.E.
Lt.-Col. Mervyn O'Gorman, C.B., D.Sc., M.I.Mech.E., M.I.E.E.
Sir Francis K. McClean, A.F.C.

HONORARY COMPANIONS

The following were appointed Honorary Companions of the Society in 1950:—

Marshal of the R.A.F. The Lord Douglas of Kirtleside, G.C.B., K.C.B., M.C., D.F.C.
Air Marshal Sir Alec Coryton, K.B.E., C.B., M.V.O., D.F.C.
Major Sir Hew Kilner, M.C.
C. G. Grey

MEDALS AND AWARDS

The following medals and awards were presented at the Thirty-Eighth Wilbur Wright Memorial Lecture on the 25th May 1950:—

The Society's Gold Medal

Sir Geoffrey de Havilland, for his outstanding work in the field of aviation.

The Society's Silver Medal

Mr. J. Smith, for his outstanding work on the design and development of high performance R.A.F. and Naval aircraft.

Mr. W. E. W. Petter, for his outstanding work on high performance aircraft —especially the Canberra (The award to Mr. Petter was made at the British Commonwealth and Empire Lecture on the 28th September).

The Society's Bronze Medal
Mr. A. C. Lovesey, for his outstanding contribution to engine development.

British Gold Medal for Aeronautics
Major F. P. Halford, for his outstanding work in the design and development of aircraft power plants.

British Silver Medal for Aeronautics
Group Captain P. W. S. Bulman and Captain J. Summers, for their long and distinguished work in the flight testing of aircraft.

George Taylor (of Australia) Gold Medal
Mr. E. J. Richards, for his paper on A Review of Aerodynamic Cleanness.

Simms Gold Medal
Dr. D. E. Adams and Dr. A. N. Uthley, for their paper on Navigational Systems and Instrument Aids.

Edward Busk Memorial Prize
Mr. P. L. Ellis, for his paper on Industrial Wind Tunnels.

Pilcher Memorial Prize
Mr. J. Hahn, for his paper on Training of Aeronautical Engineers.

Usborne Prize
Mr. C. M. Britland, for his paper on Helicopter Hovering Performance.

Orville Wright Prize
Mr. G. W. Trevelyan and Mr. D. R. Blundell, for their paper on Determination of the Drag of Jet-Propelled Aircraft in Flight.

Branch Prize
Wing Commander E. A. Harrop, for his paper on Planned Servicing in the R.A.F., read before the Brough Branch.

R. P. Alston Memorial Prize
Mr. P. Goodman, for his valuable and careful work as a Flight Observer.

BADEN POWELL MEMORIAL PRIZE

The Baden Powell Memorial Prize was awarded to Mr. B. E. Boyce, who was considered by the Society's Examiners to be the best student in the December 1949 Associate Fellowship Examination.

ELLIOTT MEMORIAL PRIZE

The Elliott Memorial Prize was awarded to 583943 Armitage, M. J., F. II. A.-Corporal, the Aircraft Apprentice of the May 1947 Entry who obtained the highest marks in the General Studies Examination; to 584266 Murray, A. R., F. II. A.-Sergeant Aircraft Apprentice, the Aircraft Apprentice of the September 1947 Entry who obtained the highest marks in the General Studies Examination; and to 584592 Boyle, D., F. II. A.-Leading Aircraft Apprentice, the Aircraft Apprentice of the January 1948 Entry who obtained the highest marks in the General Studies Examination.

ROYAL AERONAUTICAL SOCIETY CHARTER SCHOLARSHIP

The Charter Scholarship for 1950-51 was awarded to John Anthony Dunsby, B.Sc., D.I.C., Graduate. Charter Scholarships are awarded for one or two years at the discretion of the Council. J. A. Dunsby was awarded the first Charter Scholarship for 1949-50.

JOURNAL PREMIUM AWARDS

The following Premium Awards were made in 1950 for papers published in the JOURNAL during 1949:—

H. S. Crabtree, for his paper on Airlines Engineering Service Experience and its use in the Design of Aircraft, Fifteen Guineas, February 1949 Journal.

J. H. Argyris and P. C. Dunne, for their papers on The General Theory of Cylindrical and Conical Tubes under Torsion and Bending Loads, Fifteen Guineas, May and June 1949 Journals.

F. W. Page and J. C. King, for their papers on Structural Test Frame with Automatic Loading, Fifteen Guineas, October 1949 Journal.

L. W. Rosenthal, for his paper on Weight of Seaplane Floats, Fifteen Guineas, September 1949 Journal.

C. M. Britland, for his paper on Helicopter Hovering Performance.

GARDEN PARTY, 14th MAY 1950

The Society's Annual Garden Party was held on Sunday, 14th May 1950, at White Waltham Aerodrome, near Maidenhead, from 2.30 p.m. to 6.30 p.m. An account of the Garden Party was published in the July JOURNAL.

ACKNOWLEDGMENTS

The Council gratefully acknowledge the following gifts to the Society:—

A souvenir air cover carried in the "Truculent Turtle" on its record-breaking flight from Perth, Australia, to Columbus, Ohio (11,236 miles), from Lieut.-Cdr. R. F. Freitag, U.S.N., *Assoc. Fellow*.

A slide rule, calibrated for use as a rather primitive "bomb sight", which was used in the early years of the 1914-18 War, from R. R. Walls, Esq.,

A large number of valuable books, from Sir A. H. Roy Fedden, *Fellow*, Past President.

Books, periodicals and publications, from Air Commodore F. R. Banks, C.B., *Fellow*; B. Cornthwaite, Esq., *Assoc. Fellow*; J. W. Dobson, Esq. *Associate*; R. J. Lawes, Esq., *Associate*; G. Geoffrey Smith, Esq.; H. V. Stopes-Roe, Esq.; H. R. Trost, Esq.; and J. A. C. Williams, Esq., *Assoc. Fellow*.

A scrap-book of aeronautical cuttings of 1910, from R. A. Loader, Esq.

Back numbers of the JOURNAL, from the Association of Special Libraries and Information Bureaux; Miss A. D. Betts, *Companion*; Miss F. B. Bradfield, *Fellow*; H. Bradley, Esq., *Associate*; L. V. Brown, Esq., *Associate*; B. Cornthwaite, Esq., *Assoc. Fellow*; R. W. Corkling, Esq., *Assoc. Fellow*; Major G. Dennison, *Founder Member*; M. N. Dudley, Esq., *ex-Student*; Wing Commander D. M. Egan, *Associate*; R. Thompson-Holland, Esq., *Student*; W. R. Hudson, Esq., *ex-Student*; P. S. Lamb, Esq.; the National Physical Laboratory; A. Ryan, Esq., *Assoc. Fellow*; P. Saunders, Esq., *Assoc. Fellow*; G. Geoffrey Smith, Esq.; and J. Wilde, Esq.

OBITUARIES 1950

The death in 1950 of the following members of the Society is recorded with regret:—

Major T. M. Barlow, *Fellow*
Mr. H. Belart, *Assoc. Fellow*
Squadron Leader F. J. Cable, *Associate*
Mr. D. A. Coomber, *Student*
Mr. M. J. B. Davy, *Fellow*
Mr. G. W. Hart, *Founder Member*
Corporal F. Hinde, *Student*
Mr. C. L. Lawrance, *Fellow*
Major G. McAlpine, *Fellow*
Mr. H. A. Marsh, *Assoc. Fellow*
Mr. F. Murphy, *Associate*
Mr. F. L. Richards, *Assoc. Fellow*
Mr. W. H. Seabrook, *Assoc. Fellow*
Mr. E. A. Stevenson, *Associate*

REVIEW

THE SCIENCE OF PETROLEUM, VOL. V, PART I, CRUDE OILS. CHEMICAL AND PHYSICAL PROPERTIES. General Editors: Dr. B. T. Brooks and Dr. A. E. Dunstan. Oxford University Press. 1950. 199 pp. 48s. net.

It is now 12 years since the first four volumes of the Science of Petroleum appeared, and it is not surprising that developments in practically all branches of petroleum technology have necessitated the publication of further volumes to enable the "Science of Petroleum" to retain its place as the standard book of reference on Petroleum Technology.

The present book forms Part I of a series dealing with the chemistry, physics and chemical engineering of petroleum, and two further parts will subsequently be added to complete Vol. V.

Part I itself is in two sections, the first dealing with the properties and evaluation of crude oils, with a chapter on the economic developments in the petroleum industry, and the second dealing with the chemical and physical properties of petroleum hydrocarbons.

Section I contains a chapter on the U.S. crude oils from producing fields as at 1st January, 1946, analyses being given by the Standard Bureau of Mines method, with added information on the properties of fractions such as aviation gasoline.

Subsequent chapters present information on the highly important crude oils from the Middle East and from Venezuela. The chapter on the evaluation of crude oils discusses the so-called "commercial" and the "chemical" systems for the classification of crude oils, as well as Property and Yield curves of the different fractions. The final chapter in this section gives a very interesting account of the economic developments in the petroleum industry as regards sources of supply, trends in utilisation of petroleum products and raw materials, for example the ever-increasing production of chemicals, and the effect of this industry on others, either supplying constructional and transport materials or taking petroleum products.

Section 2 begins with a chapter on the separation and identification of hydrocarbons in certain petroleum fractions, and then discusses the chemistry of the different types—paraffins, naphthenes, aromatics, olefins and di-olefins. It is noteworthy that a large proportion of the chemical reactions described form the basis of processes for manufacture of chemicals. Attention should be drawn to the next chapter on the mechanism of organic reactions, which provides a clear and readable account of present thought on the application of the electronic concept to the mechanism of reactions. This has served to explain a number of otherwise inexplicable reactions, particularly the free radical effect in polymerisation initiation and propagation. A further chapter on the fractionation, analysis and isolation of hydrocarbons in petroleum overlaps, to a minor extent, the first chapter in this section, but concentrates on the work of the National Bureau of Standards Research Project No. 6, and gives detailed information on the processes used, and the hydrocarbons present, in an Oklahoma crude oil.

The penultimate chapter contains a great deal of useful data on the chemical thermodynamic properties of hydrocarbons, from which the equilibrium constants of reactions involving hydrocarbons in the gaseous state can be computed.

The final chapter presents data on the high pressure vapour liquid equilibria for use in natural gas cycling operations (returning of stripped natural gas to the reservoir).

In general, the present volume maintains the high standard set by the earlier volumes in presenting authoritative accounts of the present state of knowledge of various branches of petroleum technology. It is recommended to all who wish to maintain a reliable reference library on petroleum technology.—C.L.G.

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OF THE
ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

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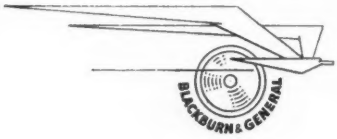

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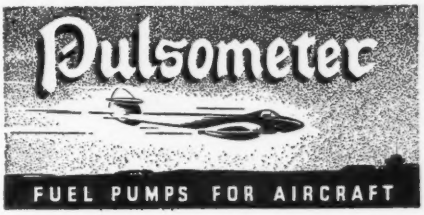

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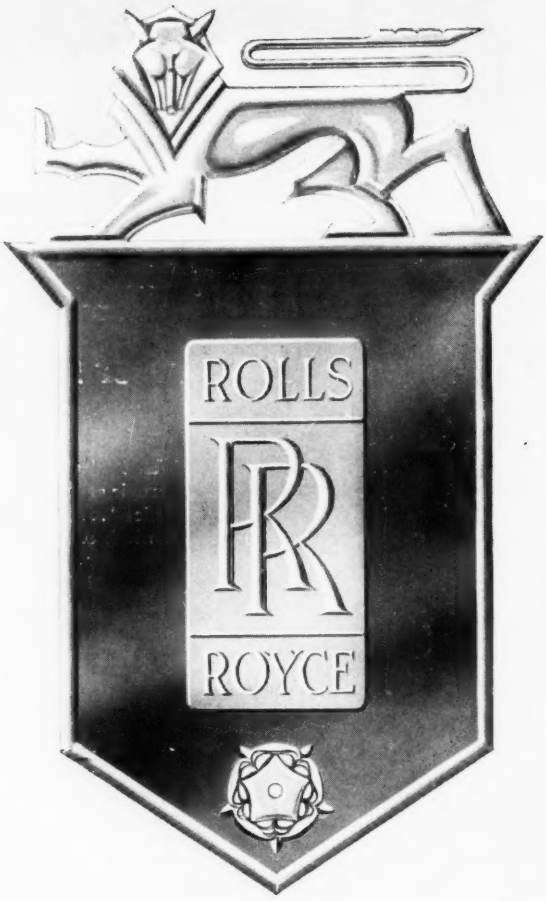

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